DEVELOPMENT OF A HYBRID PHOTOVOLTAIC-LIQUID FUELED THERMOELECTRIC GENERATOR FOR ARCTIC LOCATIONS

FINAL REPORT

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Preface

This report presents the results of Global's recent work on the development of a photovoltaic-liquid fueled thermoelectric hybrid for arctic locations. The object of this project was to develop a prototype of an integrated hybrid power and heat system to supply 90 watts of electric power and 3,000 watts of heat for arctic locations. The intended market for this type of hybrid is areas where the yearly total solar irradiation is insufficient to make photovoltaic power systems economically viable due to very long periods of very low solar irradiation. This is typical of the world's arctic and antarctic regions. The hybrid allows for significant fuel savings by using the photovoltaic source for the period that it is present.

Abstract

The solar irradiation levels in arctic and antarctic regions vary dramatically from summer to winter. It was the objective of this project to develop a photovoltaic-liquid fueled thermoelectric hybrid power system that will take advantage of the available solar irradiation during the period during which the levels are high and switch to a liquid fueled thermoelectric generator during periods when the solar irradiation levels are low. In addition the system is to provide heating to keep electronics and batteries above a preset minimum temperature. A remote start feature was designed and built into an existing liquid fueled thermoelectric generator. A prototype system was then assembled with a panel factor of about 4.88. Arctic summer conditions of solar irradiation were simulated by adjustment of the panel tilt angle. The performance of the liquid fueled generator was disappointing, numerous failures of the generator were a major impediment to the complete success of the project. It was found that the panel factor should be increased by about 15% to 20% and that the constant voltage battery recharge method is not efficient for this type of system. A cost comparison of the hybrid versus two other alternative remote power systems indicates that it is a cost-effective system.

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Executive Summary

Increasing scientific and commercial activity in the polar regions of the world is creating a market for remote unattended power supplies specifically adapted for the unique conditions of these regions. Photovoltaic systems are becoming the systems of choice at lower latitude locations. However, in arctic regions the long periods of very low or zero solar irradiation make stand-alone photovoltaic systems uneconomical in these regions. The use of a photovoltaic-liquid fueled thermoelectric hybrid was therefore investigated. This system would make use of the available solar irradiation during summer and rely on the generator during winter.

The object of this project was to develop a prototype system to supply 90 watts of electric power and about 3,000 watts of heat to keep a small equipment shelter warm. The system was to use Global's newly developed liquid fueled thermoelectric generator. A fuel savings of 40% to 50% would be required to produce a suitable payback period over a continuously operating generator.

A remote start feature was developed for the liquid fueled generator. Initial testing of the liquid fueled generator produced excellent results. However two major failures of the liquid fueled generator occurred later on in the project. These failures have placed doubt on the generator's ability to supply the reliable operation required for this type of system. A prototype system was assembled with a panel factor of about 4.88. The summer time solar irradiation levels were simulated by adjusting the panel tilt angle. A battery capacity of 540 Amp-Hr. was used. The system was set to start the generator if the battery state of charge dropped below 40% and remain on until the battery state of charge rose to 80%. Also, if the ambient temperature dropped, the generator would be started in order to supply heat to the equipment shelter.

This system was put on test and critical system parameters monitored. The results indicated that the panel factor used was too low by a factor of 15% to 20%. This would mean an increase in photovoltaic panel array size from 12 to 14 panels. It was also found that the constant voltage battery recharge method used was not very efficient. Tests showed that allowing higher recharge voltages provided faster battery recharging when the battery is above the 75% state of charge level.

A cost comparison between the hybrid system, a stand-alone photovoltaic system, and a continuously operating liquid fueled thermoelectric generator is included. The results indicate that the hybrid system would have the lowest total system cost in the 4 to 12 year life range. The hybrid system provides a balance between the high capital cost of a stand-alone photovoltaic system and the high operational cost of a continuously operating generator.

Because of the economic benefits of this type of hybrid system, it is recommended that development work on this system continue. The development of a new generation of liquid fueled thermoelectric generator which offers

greater reliability would be an important first step in the development of a successful photovoltaic-liquid fueled thermoelectric hybrid system.

Resume

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1.0 INTRODUCTION

The increasing scientific and commercial activity in the arctic and antarctic regions of the world is generating a market for remote unattended power supplies suitable for the unique environmental conditions of these regions. While there are numerous remote, unattended power supply technologies, few are truly suited to arctic conditions. In addition to the electrical power requirement, most arctic applications also require some heating in order for electronic equipment and batteries to operate efficiently and reliably. Some of the technologies which have been attempted in arctic conditions are discussed below.

One time use, primary and rechargeable batteries have been used in low power applications. Primary batteries such as zinc-air cells offer a very low power to weight ratio, and this makes the transportation cost very high. In addition, the battery size must be increased dramatically because the cells lose much of their capacity at the low temperatures. Even a small 10 watt system may require about 2 tonnes of batteries per year in an arctic application. This mass of fuel could supply 9 times as much power in a thermoelectric generator. Rechargeable batteries have yet lower power to weight ratios. Recharging can be done either by transporting the batteries to a site where A.C. power is available or by transporting a generator set to the site several times per year. Again low temperatures require the use of a high battery factor. Most rechargeable batteries do not tolerate extended periods of low charge well, thereby reducing the overall battery life in this type of service. Some types such as Ni-Cad batteries do not suffer from this but have dramatically higher cost. Both primary and rechargeable batteries cannot provide practical heating for equipment.

Reliable engine generator sets are not available in sizes under about 500 watts. Therefore, lower power demands require cycle charging of a battery bank. However, poor cold start-up performance of the engine does not provide the high degree of reliability required for unattended sites. Engine generator sets also require frequent and regular maintenance. Although engine generator sets are often used, maintenance and reliability complaints are common.

Current propane fueled thermoelectric generators can supply the reliability and low maintenance demanded by the market. These generators can be fitted with a propane pressurization and vapourization system for cold climate operation. Thermoelectric generators can also supply warm air for space heating. There are numerous such systems in operation worldwide. The major drawback to the use of propane fueled thermoelectric generators is the requirement to transport pressurized fuel to the site. This problem would be overcome by a liquid fueled thermoelectric generator.

Wind generators have been used in a few locations. However, wind generation technology is not yet fully developed. Data on the available wind power for most locations is less predictable than solar irradiation data. Because wind power cannot provide heat to keep batteries warm, battery banks must be oversized to supply enough capacity during winter.

While photovoltaic systems are becoming the system of choice at lower latitudes, stand-alone photovoltaic systems are not practical in arctic regions. The long arctic winter with very low solar irradiation requires the use of a very large battery bank which cannot be used to its full capacity due to the low ambient temperatures and unavailability of heating. Furthermore, the shortness of spring and fall days requires the use of extremely large photovoltaic panel arrays which in turn require high capacity battery charge controllers.

It is because of the shortcoming of the above systems that Global Thermoelectric Power Sytems Ltd. wished to develop the photovoltaic-liquid fueled thermoelectric hybrid. The system would take advantage of the available solar irradiation during the summer months via an array of photovoltaic panels sized to carry the load during clear days. During extended overcast periods the liquid fueled thermoelectric generator would be switched on by a low battery capacity signal. Similarly as the amount of solar irradiation drops as winter approaches, the generator will be switched on by the low battery capacity signal. Because of the lack of winter time solar irradiation in high latitude locations, the generator would remain on during the winter months.

2.0 OBJECTIVE

To develop and test a prototype photovoltaic-liquid fueled thermoelectric hybrid power system for arctic conditions using Global's newly developed liquid fueled thermoelectric generator. The system is to supply about 90 continuous Watts of electric power and provide up to 3,000 Watts (10,000 Btu/hr) of space heating in order to keep a small (2.4 m x 1.8 m) equipment shelter above -10°C for ambient temperatures down to -50°C. The system is to be completely self-controlling and suitable for unattended sites requiring no more than one service trip per year. A modular design which could be expanded in 90 Watt units was desired. In order to produce a payback period of about 4 to 5 years, a 40% to 50% fuel saving over a continuously operating generator would have to be achieved.

3.0 PROCEDURE

The nature of this project is such that it can be conveniently divided into two major subsections. The first being the development of an unattended remote start feature for the liquid fueled thermoelectric generator (LTEG). This generator was recently developed by Global. Although it is microprocessor controlled, it had not yet been developed to the point that it could be used in a true unattended remote start application. It was decided to include the start and stop logic in the LTEG microprocessor program rather than use a separate logic controller. The second subsection is the system integration of the LTEG generator, photovoltaic (P.V.) panels, battery, voltage limiter, battery charge meter and temperature control thermostat into a well functioning system.

3.1 GENERATOR DEVELOPMENT

At the onset of this project, the LTEG generator was not yet capable of highly reliable, unattended, remote starts. Although the start-up operation was automatic and microprocessor controlled, operator supervision was highly recommended. The generator was equipped with a high voltage spark plug ignition system. While this system worked relatively well, it could become impeded if the high voltage spark electrodes became soaked with fuel or carbon buildup was present. As a hybrid system would have enough power to allow the use of glow plugs, it was decided to attempt to retrofit the existing burner to a glow plug ignition system. Initial tests were very promising. The start up fuel-air mixture had to be set for a fuel rich mixture. This produced somewhat more smoke during the initial start up phase, but the amount was not considered intolerable.

Further testing of the glow plug ignition system was undertaken. During this testing 2 glow plugs failed both with less than 20 start cycles. Since these glow plugs have been life tested with much longer life times, it is believed that the failures are a result of higher than normal operational temperatures. A few different locations were tested but no practical alternative could be found which would not require a major burner redesign. Major burner redesign was outside of the scope of this project because it would require extensive reliability testing. As a result of this, the decision was made to return to the high voltage spark system.

The microprocessor software had to be altered for the remote start application. The allowable time to achieve ignition had to be increased to make up for changes in the level between the fuel pump and fuel in the tank. Previously this time was very short for safety reasons and the operator was relied on to prime the fuel system via a manual priming function to bring the fuel level up to the fuel pump. The ignition failure detection segment had to be further refined since the operator could not be relied on to shut down the system should a sudden failure occur. Rather than having a separate controller which receives signals from the battery capacity meter, thermostat and manual "on" switch in order to send a start and stop signal to the LTEG, it was decided to feed these signals directly to the LTEG and process the signals on board. Because installation in the equipment shelter will require a much longer exhaust stack, the combustion blower speed had to

be marginally increased to overcome the somewhat higher exhaust back pressure.

Test performed with the LTEG showed that electrical noise feedback problems occurred when the start up battery used is also connected to the output terminals of the LTEG generator. This was resolved by installing a relay in the output leads that will keep the output disconnected until the LTEG is in full operation and battery power is no longer needed.

The LTEG was then installed in the equipment shelter and several start-up and shut-down cycles tested. All these tests confirmed reliable functioning of the generator in the shelter.

3.2 SYSTEM COMPONENT DESCRIPTION

A block diagram of the photovoltaic LTEG hybrid is shown in Figure 1. The major components of the system and the reason for their selection are described below.

Shelter. This is the standard equipment shelter that Global normally supplies to its customers. The shelter is manufactured for Global by Intercontinental Truck Body Ltd. The shelter is of exterior 3 mm aluminum snap-lock panel construction with 50 mm styrofoam insulation and 12 mm plywood interior walls. The internal dimensions of the shelter are approximately 2.44 m by 1.83 m by 2.13 m high. The shelter is skid mounted complete with helicopter lifting lugs for easy transport.

Photovoltaic Panels. Kyocera make of photovoltaic panels were chosen because Global is Kyocera's Canadian distributor. The most commonly supplied Kyocera module is the model LA361J48 which under optimum conditions will produce 2.88 amps at a panel terminal voltage of 16.7 under full sun conditions (1,000 W/m, 1.5 air mass and 25°C). The panels are 985 mm long and 445 mm wide. A copy of the manufacturer's literature is included in Appendix A of this report. For design calculations a panel terminal voltage of 15 volts was assumed. Under this condition the panel will supply about 3 amps. If the average battery terminal voltage is assumed to be 12.2 volts, a 90 Watts load will require 7.37 amps of current. Therefore, a 12 panel array will produce a panel factor of 4.88. Further details regarding the array sizing are given in section 3.3 below.

Battery. The Exide Solar type 6E95-13 battery was chosen for this application. This is a lead acid battery with tubular positive plates and calcium negative plate construction. The battery is supplied with high electrolyte concentration, 1.300 s.g., which lowers its freezing point for cold climate applications. The battery's 48 hour capacity is 540 Amp-hour at 25°C. The capacity is reduced to 80% at -13°C. Based on 5 sun hours per day the daily depth of discharge is expected to be 26% of the 25°C capacity or 33% of the -13°C capacity. This type of battery will freeze if it is allowed to become discharged at very low temperatures. The proposed hybrid system has two features which will prevent this. The shelter will be heated by the LTEG generator which will start operation once the ambient temperature falls below -10°C and the Low Voltage Disconnect, described

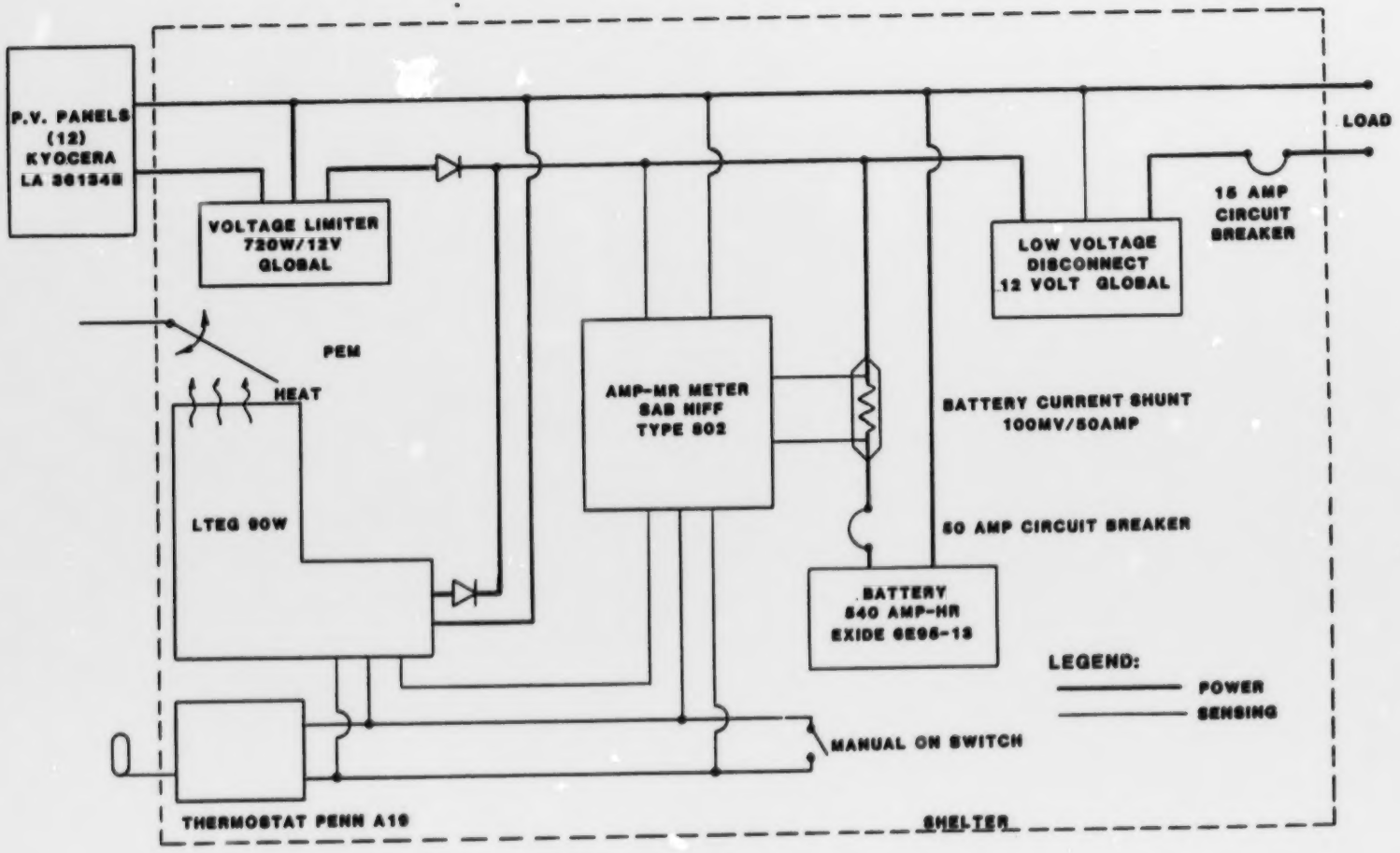


FIGURE 1 SYSTEM BLOCK DIAGRAM

below, will disconnect the load if the system voltage falls below 10.5 volts thus preserving a minimum battery charge. A copy of the manufacturer's literature is included in Appendix A of this report. Batteries which can withstand very low temperatures at total discharge such as Ni-Cad and gelled electrolyte types were found to be uneconomical for this system.

Ampere-Hour Meter. The Sab Nife Type 802 Ampere-Hour Charge Control Meter was chosen for this application, based on Global's past usage of this model. This meter monitors the battery discharge and recharge current and keeps a running total of the net battery state of charge. The battery recharge efficiency and self-discharge rate can be programmed into the meter for maximum accuracy. The ampere-hour method of battery monitoring offers greater accuracy than the terminal voltage method, especially in the mid capacity range. This is because the terminal voltage is relatively flat at mid capacity and is not only a function of the battery state of charge but also affected by battery temperature, battery load, battery age and charge hysteresis. This meter also offers a 0 to 1.0 mA analogue battery state of charge signal for remote monitoring and a set of 3 relay contacts for battery charge control. A copy of the manufacturer's literature is included in Appendix A of this report.

Voltage Limiter. The voltage limiter is Global's standard model 6720-12 limiter used with its thermoelectric generators. It is a solid-state, linear amplifier shunt type regulator. The limiter circuit senses the system voltage through a series of resistors and transistors, which act to hold the voltage level. The voltage is adjustable from 13 to 18 volts. A data sheet for the 6720 series limiter is included in Appendix A of this report.

Power Environmental Module (PEM). This is a Global designed unit used with Global's standard thermoelectric generators. It is a thermally regulated ducting system which recovers waste heat from the cooling fins of the generator for space heating. A sealed bellows actuator controls the operation of the PEM. As the shelter temperature rises, the fluid in the bellows causes the bellows to expand. The expanding bellows open a set of vents directing the warm air from the generator cooling fins outside. As the temperature drops, the vents close, directing the warm air inside. For this system, an exhaust heat exchanger was added to make use of both the cooling air and exhaust waste heat. A total of about 3,000 Watts (10,000 Btu/hr) of heat should be available for shelter heating.

Low Voltage Disconnect. This is a Global designed device. Its purpose is to protect the battery from total discharge in the event of a power supply failure. It will disconnect the load if the system voltage falls below 10.5 volts. The load is reconnected once the voltage returns to about 12.5 volts.

Thermostat. A Penn Series A19 thermostat was chosen for this application. It is a remote vapour bulb SPDT type thermostat which offers a wide set point range, -34°C to +38°C, and a wide adjustable differential range 1.7°C to 6.7°C. Because this thermostat is usually used for cooling applications, the set point determines the temperature at which the LTEG operation will

stop, and the differential is used to determine number of degrees below the set point at which the LTEG should start.

3.3 P.V. PANEL ARRAY SIZING AND TILT ANGLES

The day-long solar irradiation for a tilted surface at 64° North latitude is shown in Figure 2. The data for this figure was adapted from ASHRAE [1]. It can be seen that the day-long irradiation varies dramatically during the year at this latitude from essentially zero during December to a high above 6,000 W-hr/m^2 for about 6 months in the summer. Three tilt angles are shown, 54°, 64° and 74°, representing the latitude minus 10°, latitude, and latitude plus 10° positions. It can be seen that an angle of 64° provides significantly more power than 74°. Lowering the angle further to 54° will provide yet more peak power in June but has little positive effect on the accumulative output over the summer season. For this reason an angle of 64° was assumed. It is interesting to note that outside the March to October period there is very little difference in day-long irradiation between the three angles.

In order to produce similar conditions at Global's test location, 51° North, the tilt angle was adjusted to produce peak values of day-long irradiation close to that of 64° tilt at 64° North. It was found that a tilt angle of 55° will produce this condition. Figure 3 compares the day-long irradiation pattern between a 55° tilt at a 51° North location and 64° tilt at 64° North location. It can be seen that the peak summer values are very close and the 55° tilt at 51° North produces two peaks. As indicated in section 3.2 above, the panel array is sized for a panel factor of 4.88. Since the normal terrestrial value of solar irradiation is about 1,000 W/m^2, 24 hours of direct sun would produce 24,000 W-hr/m^2 per day. A panel factor of 4.88 therefore requires a minimum of 4,918 W-hr/m^2 per day of solar irradiation in order to support the load. This is represented by the line drawn across Figure 3.

3.4 SYSTEM MONITORING

The test points which were monitored are shown in the instrumentation diagram, Figure 4. Initially the system data was recorded manually and 2, 57 Watt 12 Volt lamps were used as a load. Later on the test points were connected to a data acquisition system which printed out a set of data every 6 minutes of the past 6 minute average value of generator gross and net power, panel current, battery current, battery voltage, load power, percent battery capacity, ambient temperature, generator fin temperature, and shelter inside temperature. In addition, at the bottom of each page a total of the panel, negative battery, and positive battery currents are printed to simplify totalling. Unfortunately the Amp-Hour Meter's battery capacity signal moves in 10% increments, and therefore the actual reading had to be manually recorded from time to time. A sample data print out is included in Appendix B. At the same time as the data acquisition system was installed, the load was replaced with a constant current electronic load set at 7.4 Amp.

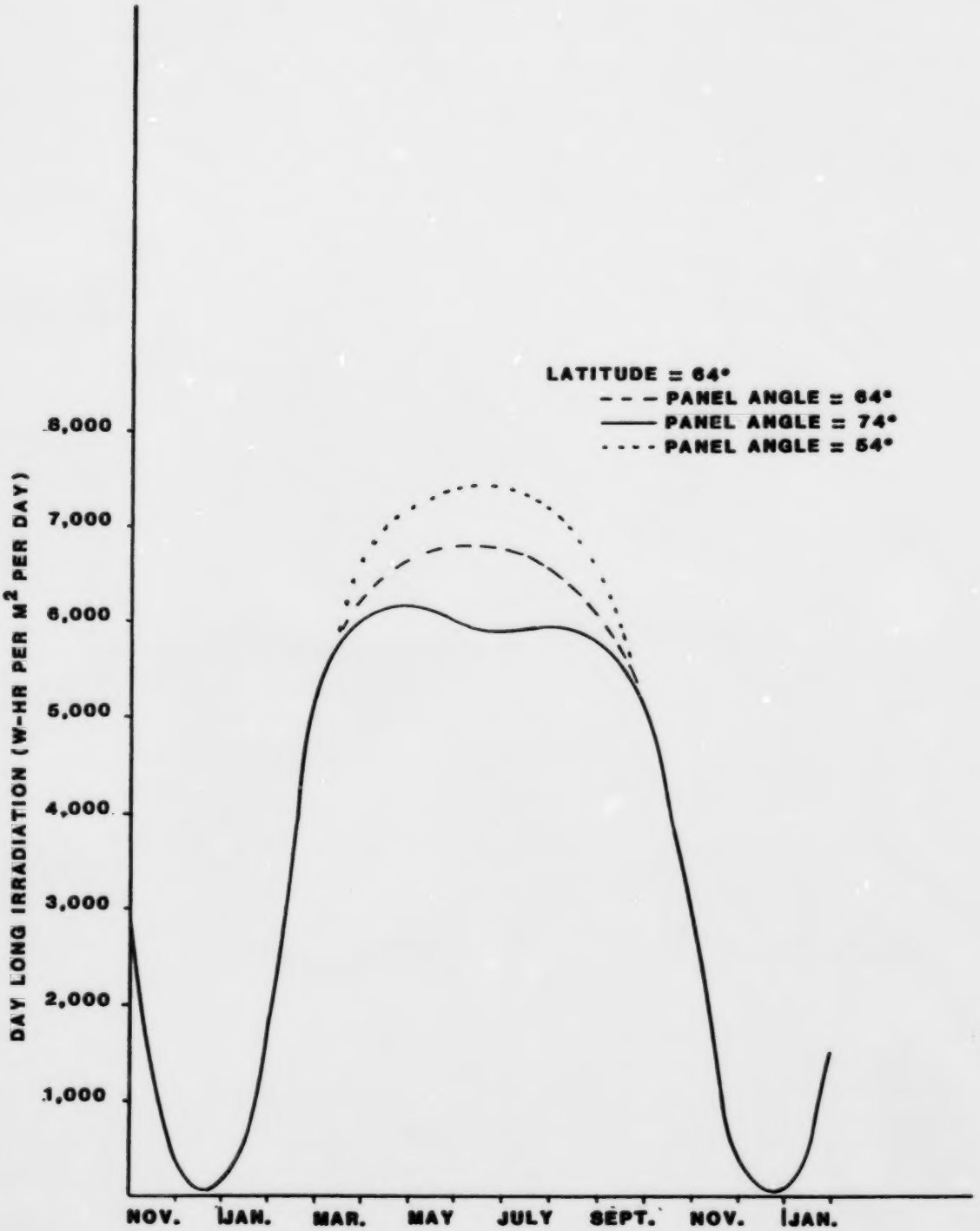


FIGURE 2 DAY LONG IRRADIATION AT 64° NORTH

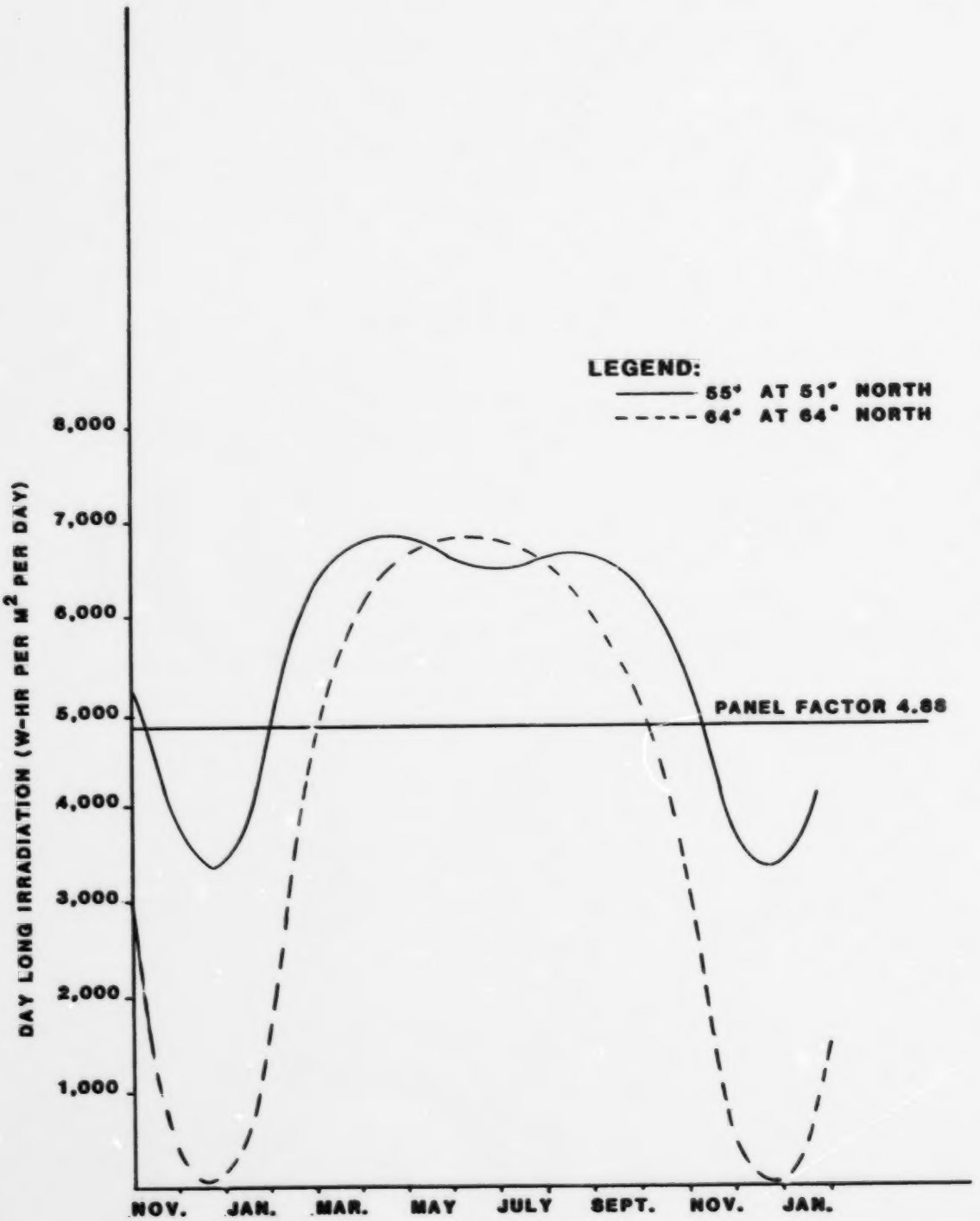


FIGURE 3 DAY LONG IRRADIATION FOR 55° AT 51° NORTH AND 64° AT 64° NORTH

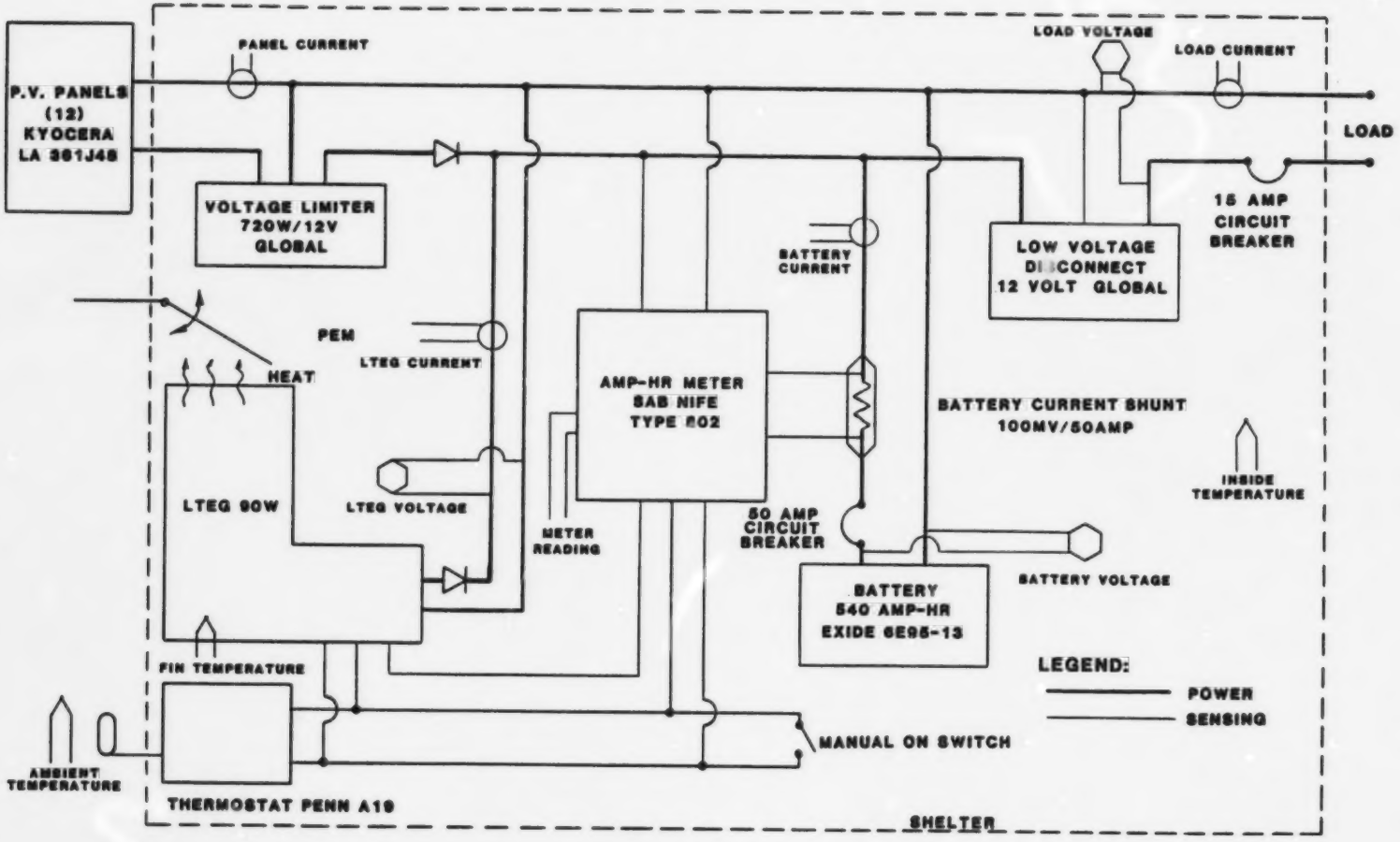


FIGURE 4 INSTRUMENTATION DIAGRAM

4.0 RESULTS

4.1 SHELTER HEATING

The heating thermostat was set to turn on the generator for heating if the ambient temperature fell below -10°C and remain on until it rose above -3°C. A heat loss calculation of the building indicated that the expected heat output of 3,000 Watts should be sufficient to maintain a temperature differential of 40°C. Unfortunately the winter of 87/88 was very mild and produced only a few days of below -30°C weather. This did not allow for extensive testing of the shelter heating system. For a short period at the beginning of February the overnight temperature fell to -30°C. At this temperature the ventilation door on the PEM was fully closed and the inside temperature with the generator operating was held at about +10°C. As soon as the ambient temperature rose to -20°C the ventilation door on the PEM would start to open slightly and maintain a temperature of 15°C to 18°C. Although this test was of a very short duration, it indicates that the required 40°C temperature differential can be obtained. It was also noted that the shelter air temperature was strongly stratified indicating that more air circulation may be needed. During hot sunny days the shelter temperature tends to get into the mid 30's. Again more air circulation would help keep the inside temperatures down.

4.2 SYSTEM OPERATION

Initially the system was programmed to start the generator if the battery capacity fell below 80% or the ambient temperature fell below -10°C. The generator would remain in operation until both the battery capacity was at 100% and the ambient temperature was above -3°C. The 80% capacity start signal would eventually be lowered but was initially set this high in order to induce numerous generator starts. The voltage limiter was set for the battery trickle charge voltage of 13.6 volts. This mode of operation revealed a serious problem. Because the amount of current the battery will accept at a given voltage drops off as it becomes charged, it takes a long time for the battery to get from the 90% state of charge (S.O.C.) to the 100% S.O.C. level in a constant voltage mode of charging. For this reason the generator off signal was reset to 90% S.O.C., and the on signal to 70% S.O.C. The initial load of 115 Watts was higher than the design load of 90 Watts again in order to produce more start cycles for the generator. The system was allowed to operate in this mode for several months. This mode of operation produced numerous successful start-up cycles of the generator during the period from November, 1987 to January, 1988.

It was found that when the battery was in the 70% to 100% S.O.C. it would not accept all the available current from the photovoltaic panels in the constant voltage mode. This resulted in incomplete usage of the available photovoltaic power. In order to evaluate more effective ways to recharge the battery, the voltage limiter was removed and the photovoltaic panels connected directly to the battery system. With the battery in the 70% to 75% S.O.C. range and about 31 amps of available photovoltaic current, the battery received about 23 to 24 amps of charging current. At the same time the battery held the system voltage at about 14.7 volts. The remaining 8 to

7 amps of current was used to support the load and Amp-Hour Meter. Under similar conditions with the voltage limiter connected the charging voltage would be limited to about 13.7 volts and the battery would receive only about 13 amps of charging current. This test was repeated several times with similar results. The data indicates that the limiter will start to dump some of the available photovoltaic panel current in order to maintain 13.7 volts when the battery is above the 70% S.O.C. range. The amount of unused current rises even more as the battery 100% S.O.C. level is reached. However, the photovoltaic panels may not remain connected to the battery once it has reached the 100% S.O.C. as this will produce severe gasing of the electrolyte.

During April the Amp-Hour Meter readings were monitored in order to determine their accuracy. Over several time periods the sum of the charge and discharge currents recorded by the data acquisition system agreed fairly well with the Amp-Hour Meter readings. Errors in the 2% to 3% range were noted, but these errors are within the expected accuracy of the data acquisition system. Since the Amp-Hour Meter resets itself at a 100% S.O.C. reading this amount of error should not be a problem.

Figures 5, 6, 7 and 8 show the daily photovoltaic panel current in Amp-Hr and the morning and evening battery S.O.C. for April, May, June and July respectively. It can be seen that as long as the daily photovoltaic current remains above 190 Amp-Hr per day the battery S.O.C. remains level. Also indicated are several periods when the load was removed; this simulates periods during which the generator would be operating. During the first such period in May the battery S.O.C. rose from about 45% to 95% in 3 days. During the next period in June the capacity rose from 0% to 90% in 2 days. In the second week of July the load was again turned off and the battery capacity rose from 20% to 80% in 3 days. These periods were preceded by several days of cloudy weather. This would indicate that with a panel factor of 4.88 the generator would still be required to operate 2 to 4 days every month.

4.3 GENERATOR OPERATION

Initially the Liquid Fueled Thermoelectric Generator (LTEG) operated very well. The remote unattended start feature developed, in part under this program, appeared to be performing satisfactorily. The LTEG had functioned well for several months when a major failure occurred. At the end of December, 1987 as the LTEG attempted to start, one of the traces on the microprocecssor board burned out. As this was a fairly wide trace, there must have been a very high current present. Although the exact cause for this was never fully resolved, it is believed that a faulty output diode in the generator's voltage limiter allowed the battery to short circuit through the microprocessor board and ignitor ground circuit. This board was replaced and an additional fuse placed in the negative side of the start-up circuit. This problem never reoccurred, and the additional fuse was never triggered. The damaged board was later tested, and no error in its function could be found.

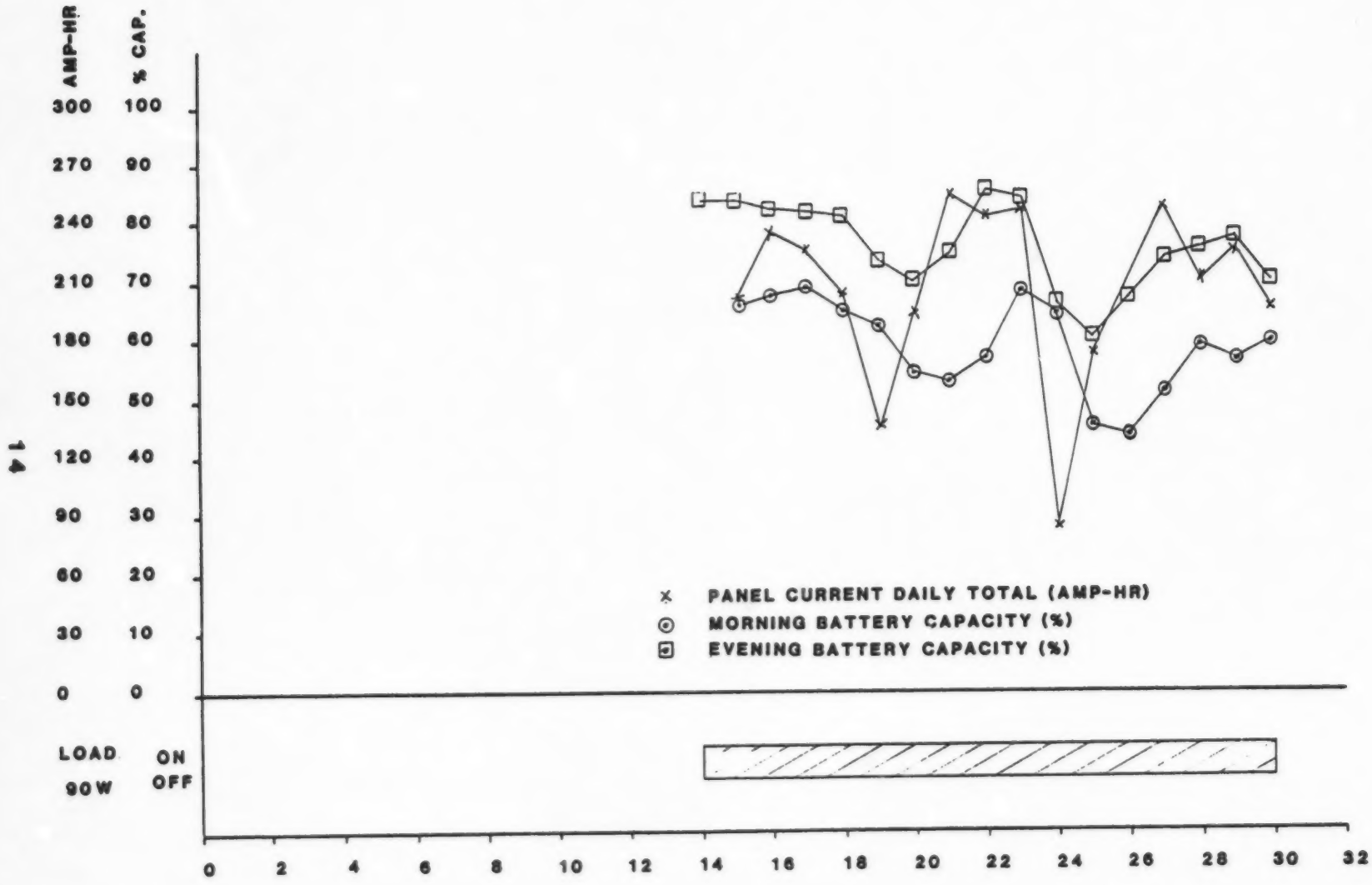


FIGURE 5 RESULTS FOR APRIL 1988

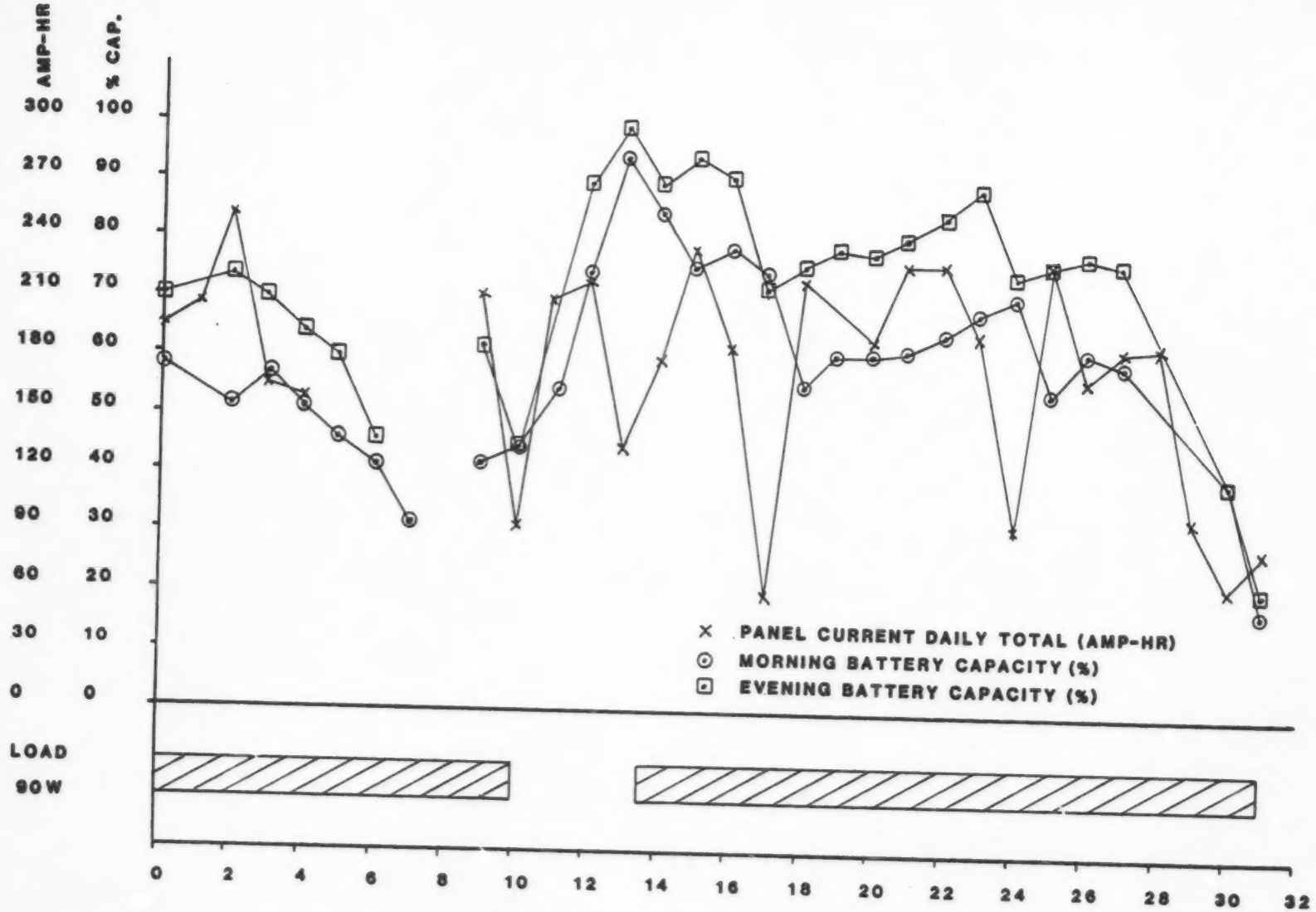


FIGURE 6 RESULTS FOR MAY 1988

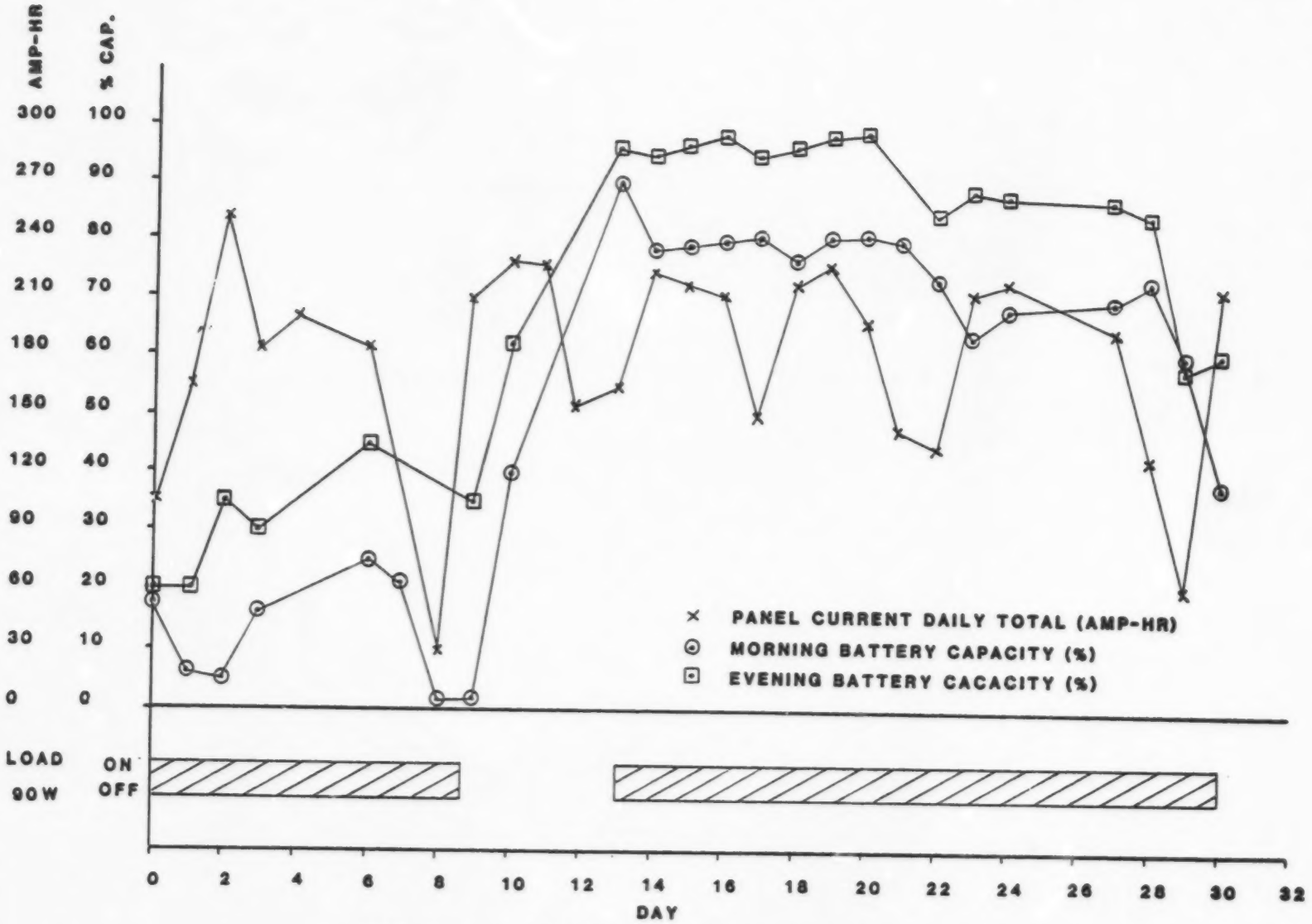


FIGURE 7 RESULTS FOR JUNE 1988

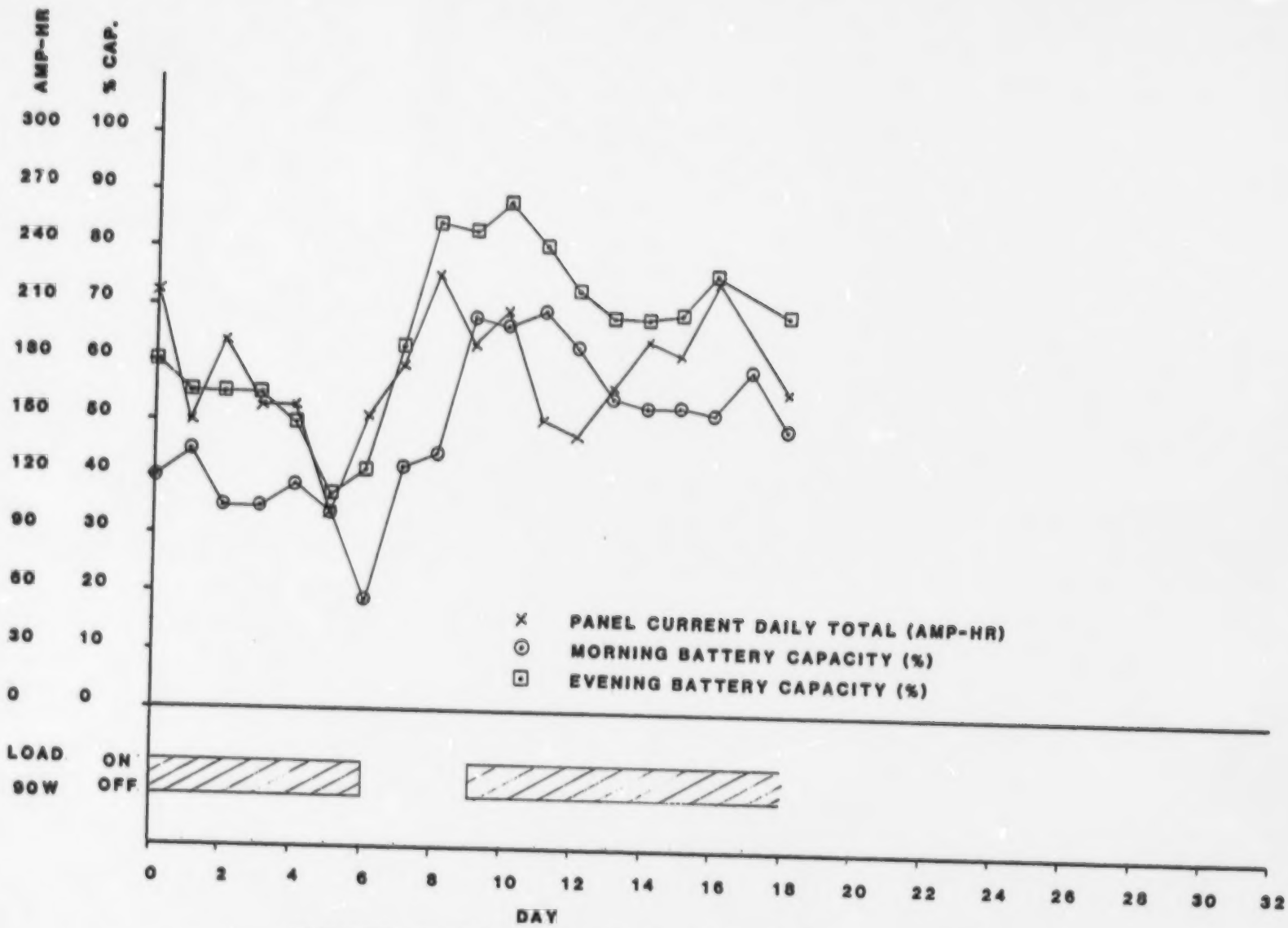


FIGURE 8 RESULTS FOR JULY 1988

Toward the end of the project another failure of the LTEG occurred. It appeared that a fire developed in the burner air tube after about 1-1/2 hours of normal operation. The fire melted away the plexiglass viewing window on the end of the air tube, thereby charring the control electronics board. Fortunately the fuel flow was stopped in time to prevent further damage. Due to the unavailability of a replacement unit and the closeness of the project completion date, no further work was done on the generator. The system was operated without the generator for data collection purpose.

4.4 DISCUSSION OF RESULTS

The fact that the photovoltaic panels did not supply sufficient current to supply the load in April, May, June and July would indicate that the array size needs to be increased. Since the load had to be turned off about 3 days per month in this period, a deficit of about 10% is indicated. This deficit could be overcome by increasing the array size from 12 to 14 panels, thereby increasing the panel factor to 5.70 from 4.88. It was also found that when the battery is in the 75% S.O.C. or higher, not all the available current would go into the battery in the constant voltage mode of operation. This result indicates that the battery would recharge more rapidly if the photovoltaic panel output voltage was not limited until the battery end of charge voltage was reached, about 15.5 volts, or the Amp-Hr Meter indicated 100% S.O.C. At this point the photovoltaic panels must be disconnected completely or the voltage limited to a trickle charge voltage, about 13.5 volts, to prevent boiling of the electrolyte. The trickle charge voltage would be preferred as it would allow the battery to continue to charge in case of an error in the S.O.C. or voltage reading. With the above changes it is estimated that the generator would operate about 60% of the time over a one year period at a 64° North location.

The results indicate that the Amp-Hour Meter is a reliable method of monitoring the battery S.O.C. However, more flexibility in its programming would be desirable. Things like providing both normally open and normally closed contacts on S.O.C. relays and supplying a continuous 0-1 mAmp S.O.C. signal would make system design easier.

The two major failures of the LTEG generator are disappointing. These failures indicate that the system design of the liquid fueled thermoelectric generator requires a major redesign. It is believed that the control system is too complex and could be simplified to make it more reliable. However for the time that the generator did operate, the system worked well as an integrated unit.

Recently Global has concentrated liquid fuel combustion development on a state-of-the-art thermoelectric generator. This new product is called the Manpack II and has many advantages over the LTEG. Firstly, the Manpack II is designed from the ground up to burn liquid fuel, not a modified gas fueled generator. Secondly, the Manpack II produces 12 VDC nominal and can be placed in parallel with the Hybrid's Batteries and Solar Panels. This greatly simplifies all aspects of control, particularly start-up of the Manpack II. Some modifications could be made to increase performance and reliability, such as natural convection cooling, instead of forced air

cooling. Yet even without any modifications the Manpack II will provide a more reliable Hybrid system with an increased power rating of 120 Watts continuous.

4.5 COST COMPARISON

In order to determine the economical cost benefit to the end user of this type of photovoltaic hybrid, the capital cost and yearly operational cost of two alternative systems will be compared and the payback period and lifetime costs calculated. The two systems used for this comparison are a stand-alone photovoltaic system for Fort Simpson at 62° North based on sizing data from the Kyocera manual [2] and a continuous use liquid fueled thermoelectric generator. Only those costs which are needed to make the comparison are included, and cost common to all systems has been excluded. The cost of the PEM heating system is not included for the hybrid and generator system as it provides additional benefits to the user for which a monetary value cannot easily be determined. The costing factors used are as follows:

Battery	$2.90 per 12 volt amp-hr
Photovoltaic Panels	$140 per 12 volt amp peak power
Fuel	$1.40 per litre delivered to site
Battery Size	540 Amp-Hr for hybrid 4700 Amp-Hr for stand-alone photovoltaic
Battery Factor	1.4 for heated (hybrid) 2.5 for unheated
Panel Factor	6 for hybrid 18 for pure photovoltaic
Fuel Consumption	10.5 litres per day
Load	7.5 Amp

Stand-alone Photovoltaic:

Photovoltaic Panels	
7.5 Amp x 18 x $140 per amp =	$18,900.00
Battery	
4700 Amp-hr x 2.5 x $2.90 per Amp-hr =	34,075.00
Voltage Limiter	2,000.00
Total Capital	$54,975.00
Yearly Operational	NIL

Generator Only:

Generator	$10,000.00
Fuel Tank (4,000 l)	850.00
Total Capital	$10,850.00

Yearly Fuel Cost

10.5 l per day x 365 days x $1.40 per l =	$ 5,365.50

Hybrid System:

Photovoltaic Panels	
7.5 Amp x 6 x $140 per Amp =	$ 6,300.00
Battery	
540 Amp-Hr x 1.4 x $2.90 per Amp-Hr =	2,192.40
Limiter	1,000.00
Generator	10,000.00
Amp-Hr Meter	1,000.00
Fuel Tank (2200 l)	550.00
Total Capital	$21,042.40
Yearly Fuel Cost (200 days ie 55%)	
10.5 l per day x 200 days x $1.40 per l =	$ 2,940.00

These results are summarized in Table 1 below. Also indicated is the payback period without capital amortization relative to the generator only system.

TABLE 1 COST COMPARISON AND PAYBACK

System	Capital Cost $	Yearly Operational $	Payback vs. Generator Years
Photovoltaic	54,975.00	Nil	8.2
Generator Only	10,850.00	5,365.50	-
Hybrid	21,042.40	2,940.00	4.2

The lifetime cost versus the system life is shown in Figure 9. From Figure 9 it can be seen that the hybrid system presents the lowest cost in the 4.2 to 11.5 years life range. The generator only system produces the lowest cost in the under 4.2 years life period. It is not until after 11.5 years that the stand-alone photovoltaic system produces a cost saving compared to the hybrid system. The hybrid system provides a balance between the high capital cost of the stand-alone photovoltaic system and high fuel cost of the continuously operating generator.

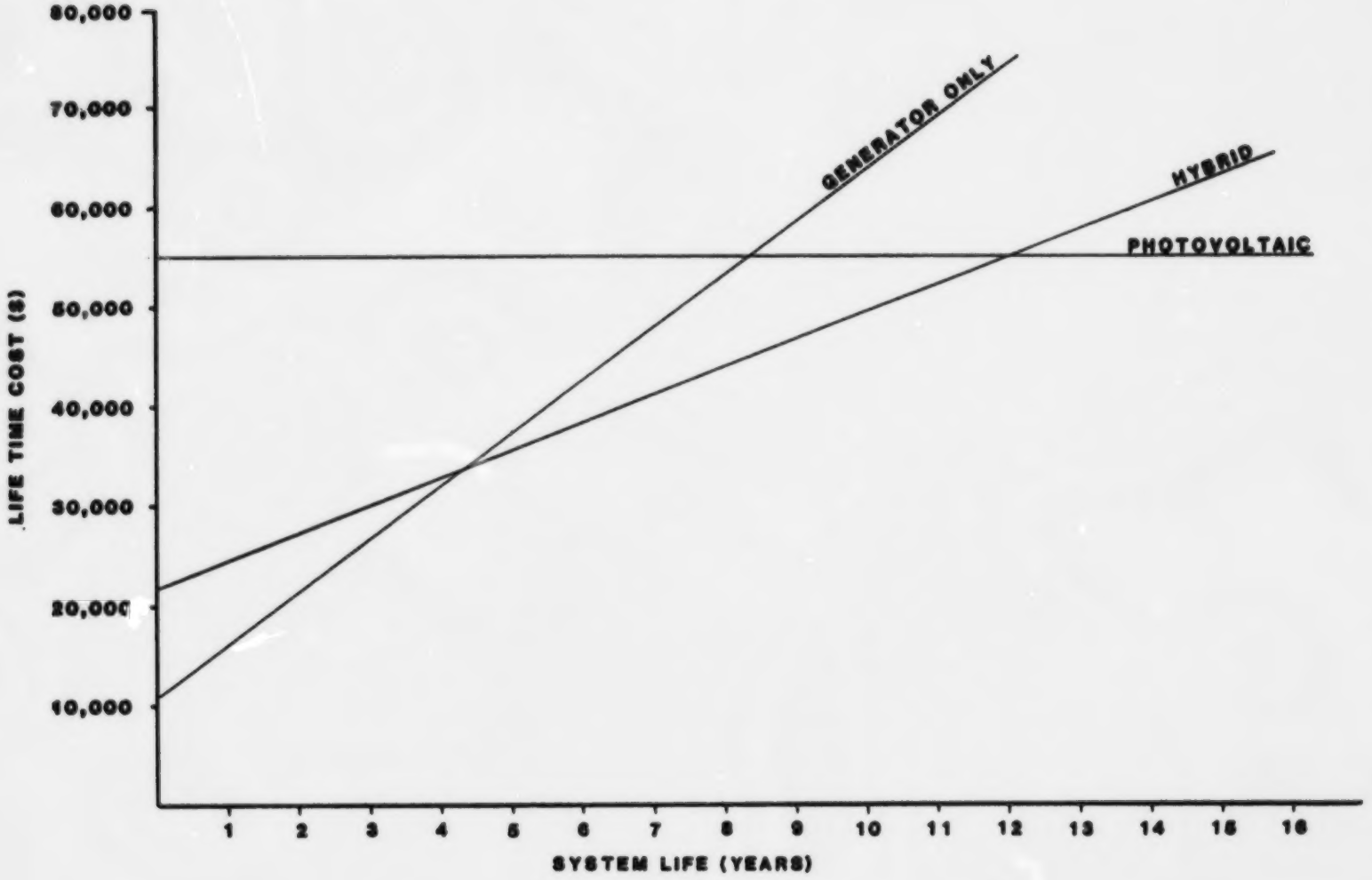


FIGURE 9 LIFE TIME COST COMPARISON

5.0 CONCLUSIONS

The objectives of this project were not fully met. However, the results of this project have made significant advances to proving the viability of photovoltaic-liquid fueled thermoelectric hybrids for arctic locations. The major impediment has been the failure of the liquid fueled thermoelectric generator. At the onset of this project it was believed that this unit was reliable enough to be used as the back-up power source for this system. However, this has not been the case. Two other problems have been identified. The panel factor of 4.88 has been shown to be too low to supply the load during the summer months and should be increased to about 6 for the design latitude of 64°. The constant voltage trickle charge mode of battery recharging has been shown to be inefficient and should be replaced by a system which would allow higher recharge voltage until the battery is fully charged. The battery capacity of 540 Amp-Hr appears to be sufficient for this system.

In spite of the shortcomings, this project did serve to demonstrate the concept of photovoltaic-liquid fueled thermoelectric hybrid systems.

This type of system provides a balance between the high capital cost of a photovoltaic system and the high operational cost of a continuously operating generator in arctic locations. A comparison of the hybrid system with two other remote power options shows that the hybrid provides the lowest lifetime cost for a system life of 4 to 12 years.

6.0 RECOMMENDATIONS

The results of this project have shown promise. It is therefore recommended that development of the photovoltaic-liquid fueled thermoelectric generator hybrid be continued to the point where it will be a commercial product. The problems encountered to date are by no means insurmountable. In order to ensure future success, a much more reliable liquid fueled thermoelectric generator must be used. The emphasis must be on a simple and reliable control system. The constant voltage battery recharge system should be replaced with a more efficient system. Such systems are presently available. The next system should have a panel factor of about 6 so that it will be able to carry the load during the summer months.

REFERENCES

[1] ASHRAE, "Handbook, Applications 1978" American Society of Heating, Refrigeration and Air Conditioning Engineers, New York, 1978, pp. 58.6-58.7

[2] Kyocera, "Design Manual" Kyocera International, Albuquerque, New Mexico.

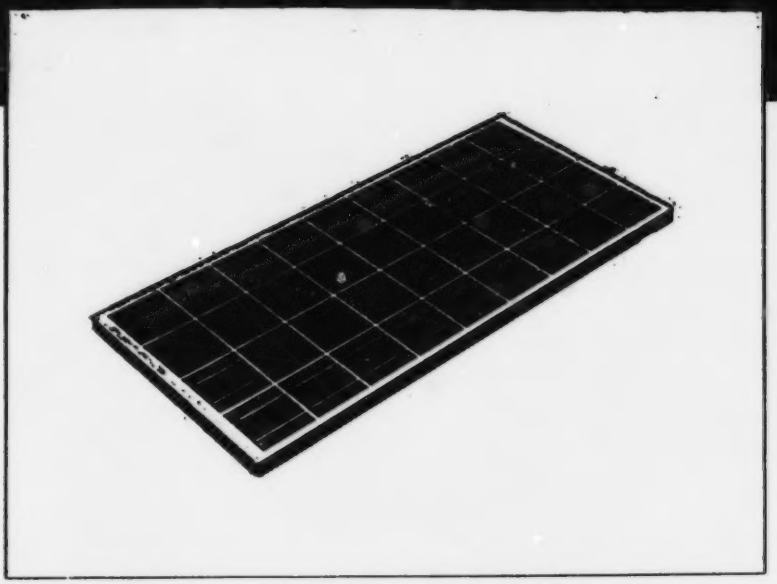
APPENDIX A

MANUFACTURER'S LITERATURE

LA361J48

HIGH EFFICIENCY MULTICRYSTAL PHOTOVOLTAIC MODULE

TYPICAL OUTPUT 48.0 Wp



HIGHLIGHTS OF KYOCERA PHOTOVOLTAIC MODULE

Kyocera's cell processing technology has produced a remarkable high efficiency multicrystal solar cell thanks to innovation and highly automated production facilities.
The conversion efficiency of the Kyocera solar cell is over 13%.
These cells are encapsulated between tempered glass cover and EVA pottant with PVF and aluminum foil back sheet to provide maximum protection from severest environmental conditions.
The entire laminate is installed in an anodized aluminum frame to provide structural strength and ease of installation.

APPLICATIONS

Microwave/Radio repeater stations
Electrification of villages in remote areas
Medical facilities in rural areas
Power source for summer house and cottages
Emergency communication systems during disasters
Water quality and environmental data monitoring system
Navigation lighthouses, beacons and ocean buoys
Illumination for indicating board
Pumping systems for irrigation, rural water supplies and livestock watering
Aviation warning lights
Cathodic protection system
Desalination system
Fish luring buoys
Camping car
Railroad signals
Boat
Various other application systems

SPECIFICATION

■ Electrical Specification

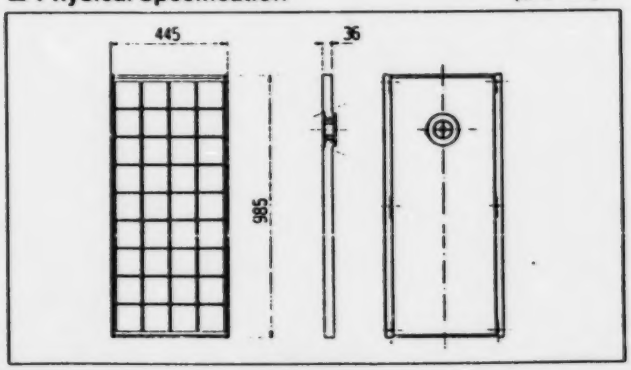
MODEL	LA361J48
Output	48.0 Watts
Optimum Voltage	16.7 Volts
Optimum Current	2.88 Amps
Open Circuit Voltage	20.7 Volts
Short-Circuit Current	3.10 Amps
Length	985 mm
Width	445 mm
Depth	36 mm
Weight	5.9 kg

Note: The electrical specifications are under test conditions of Irradiance of 100 mW/cm², spectrum of 1.5 air mass and cell temperature of 25°C at typical

Kyocera reserve the right to modify these specification without notice
Custom made laminate and module are also available upon particular request

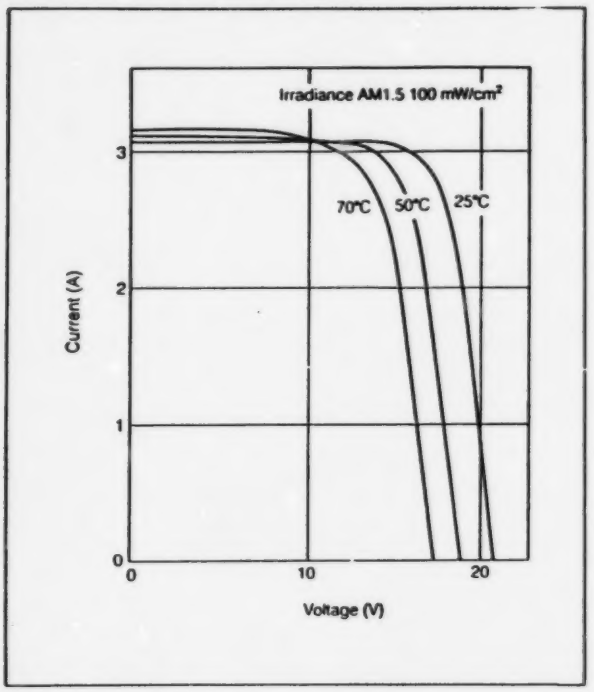
■ Physical Specification

(Unit: mm)

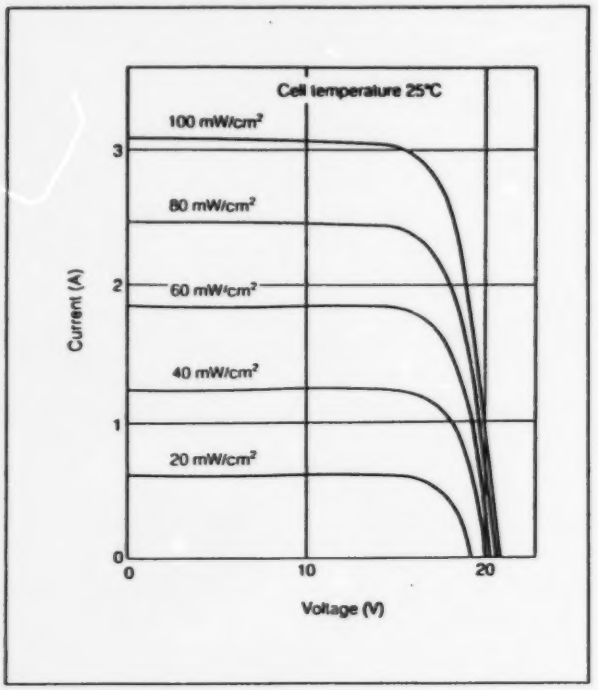


ELECTRICAL CHARACTERISTIC

Voltage-Current characteristics of Solar Module LA361J48 at various temperatures



Current-Voltage characteristics of Solar Module LA361J48 at various irradiance levels



QUALITY ASSURANCE

Reliability of Kyocera multicrystal photovoltaic module is proved to be exceeding government specification with given below tests.

- Thermal cycling test
- Thermal shock test
- Thermal/Freezing and high humidity cycling test
- Electrical isolation test
- Hail impact test
- Mechanical, wind and twist loading test
- Salt mist test
- Light and water-exposure test
- Field exposure test

KYOCERA

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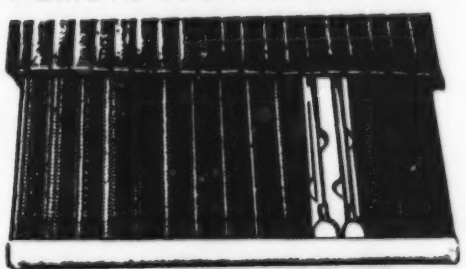
22 Shenton Way, 03-37 ICB Bldg, Singapore
Phone: 220-7813 Telex: 20133

EXIDE®

Tubular Modular Batteries for Shallow Cycle Solar

Features

- ☐ TUBULAR POSITIVE PLATES FOR OUTSTANDING CYCLING CAPABILITY IN LESS SPACE
  - ☐ Up to 3800 20% Discharges Available
  - ☐ Active Materials Locked Inside Tubes
  - ☐ Special Lead-Oxide Blend Packs Maximum Power Per Ounce of Active Material
  - ☐ Electrolyte has Free Access to the Active Material Through Tubes
- ☐ CALCIUM NEGATIVE PLATES—
  - ☐ Minimum Self Discharge
  - ☐ Reduced Water Loss
  - ☐ Lower Maintenance
- ☐ LONG LIFE—UP TO 10 YEARS IN SHALLOW CYCLE SERVICE
- ☐ SIZES 180 to 1750 A.H. ELIMINATE PARALLEL STRINGS
- ☐ FLAME ARRESTORS STANDARD
- ☐ OPTIONAL FLAME ARRESTOR WITH ACID LEVEL INDICATOR AVAILABLE
- ☐ EASILY DISASSEMBLED/ASSEMBLED WITH SIMPLE HAND TOOLS—FOR REMOTE LOCATION TRANSPORT.



TUBULAR POSITIVE PLATE

Applications (3 Days to 21 Days)

- ☐ SHALLOW CYCLE PHOTOVOLTAIC
  - ☐ Microwave
  - ☐ Rail Signal
  - ☐ Cathodic Protection
  - ☐ Communications
- ☐ SHALLOW CYCLE WIND
  - ☐ Microwave
  - ☐ Communications
- ☐ AVAILABLE
  - ● Charged and Wet
  - ● Dry Charged

SPECIFICATIONS

Module Dimensions — Weights:

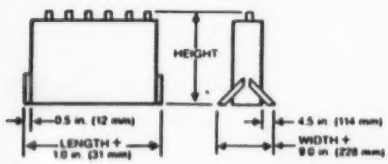
TYPE	NOM. A.H. CAP.	CAT. NO.	VOLTAGE PER MODULE	OVERALL DIMENSIONS						WET WEIGHTS—VOLUMES PER CELL							
				LENGTH		WIDTH*		HEIGHT**		UN-PACKED		DOMESTIC PACKED		ELECTROLYTE ONLY 1.300 SP. GR			
				in.	mm	in.	mm	in.	mm	lbs.	kg	lbs.	kg	lbs.	kg	gal.	l
6E95-5	180	89447	12	14.5	368	7.75	197	28.0	711.0	193	88	212	96	8	3	.74	2.8
6E95-7	270	89448	12	19.0	483	7.75	197	28.0	711.0	261	118	287	130	10	4	.92	3.5
6E95-9	360	89449	12	23.5	597	7.75	197	28.0	711.0	329	149	362	164	12	6	1.15	4.4
6E95-11	450	89450	12	28.0	711	7.75	197	28.0	711.0	404	183	444	202	15	7	1.38	5.2
6E120-9	500	89451	12	23.5	597	7.75	197	32.5	825.5	425	193	467	212	14	6	1.29	4.9
6E120-11	625	89452	12	28.0	711	7.75	197	32.5	825.5	500	227	550	250	18	8	1.66	6.3
6E120-13	750	89453	12	32.5	825	7.75	197	32.5	825.5	604	274	664	301	21	9	1.93	7.3
6E120-15	875	89454	12	37.0	940	7.75	197	32.5	825.5	702	318	772	350	25	11	2.30	8.7
3E120-17	1000	89455	6	22.0	559	7.75	197	32.5	825.5	403	183	443	201	29	13	2.67	10.1
3E120-19	1125	89456	6	25.0	635	7.75	197	32.5	825.5	452	205	497	225	32	14	2.95	11.1
3E120-21	1250	89457	6	26.5	673	7.75	197	32.5	825.5	492	223	541	245	36	16	3.32	12.6
3E120-23	1375	89458	6	29.5	749	7.75	197	32.5	825.5	542	246	596	270	40	18	3.68	13.9
3E120-25	1500	89459	6	31.0	787	7.75	197	32.5	825.5	585	265	643	292	43	19	3.96	15.0
3E120-27	1625	89460	6	34.0	864	7.75	197	32.5	825.5	628	285	691	313	47	21	4.33	16.4
3E120-29	1750	89461	6	35.5	902	7.75	197	32.5	825.5	677	307	745	338	51	23	4.70	17.8

*Allow 9" additional clearance for removable support legs (see layout dimensions).

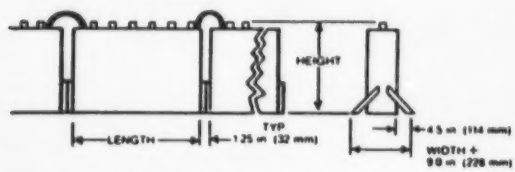
**Allow additional 2" (50.8 mm) height when using optional acid level indicator/flame arrestor.

Layout Dimensions:

BASE UNIT WITH REMOVABLE SUPPORT LEGS



END-TO-END LAYOUT



SIDE-TO-SIDE LAYOUT

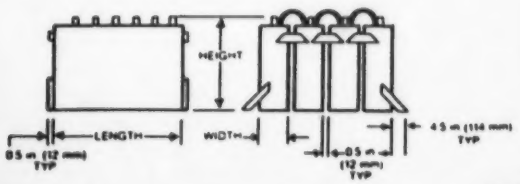


Plate Dimensions:

TYPE	NOM. A.H. CAP.	HEIGHT				WIDTH				THICKNESS			
		POS.		NEG.		POS.		NEG.		POS.		NEG.	
		in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm
E95	90	16.5	419	16.0	406	5.75	146	5.7	145	.36	9.1	.20	5.0
E120	125	22.0	558	21.7	551	5.75	146	5.7	145	.36	9.1	.20	5.0

CELL TYPE	E95		E120-9 to 15		E120-17 to 29	
ELECTROLYTE OVER PLATES	in.	mm	in.	mm	in.	mm
	3.1	80	1.9	47	1.9	47
SEDIMENT SPACE	2.7	70	2.0	51	2.0	51
POSTS/CELL	2		2		4	
MODULE, CONTAINER AND COVER MATERIAL	POLYPROPYLENE					
SEPARATOR MATERIAL	MICROPOROUS POLYETHYLENE					
PLATE SUSPENSION	BOTTOM SUPPORTED					
SPECIFIC GRAVITY	1.300					
BOLT CONNECTORS 'L' TYPE	¼-20 x 1" (S.S.)					
VENT TYPE	FLAME ARRESTOR, FUSED ALUMINA					
INTERUNIT CONNECTORS	#1/0 CABLE-14 in. (355 mm)					
INTERCELL CONNECTORS	LEAD-PLATED COPPER					

AVERAGE CELL PERFORMANCE DATA

Discharge Rates in Ampere Hours and Amperes.

- **1.300 Specific Gravity Electrolyte**
- **1.250 Specific Gravity Electrolyte Available For Annual Temperatures Greater Than 90°F (32°C)—Reduce Ratings by 10%.**

To 1.90 Volts Per Cell

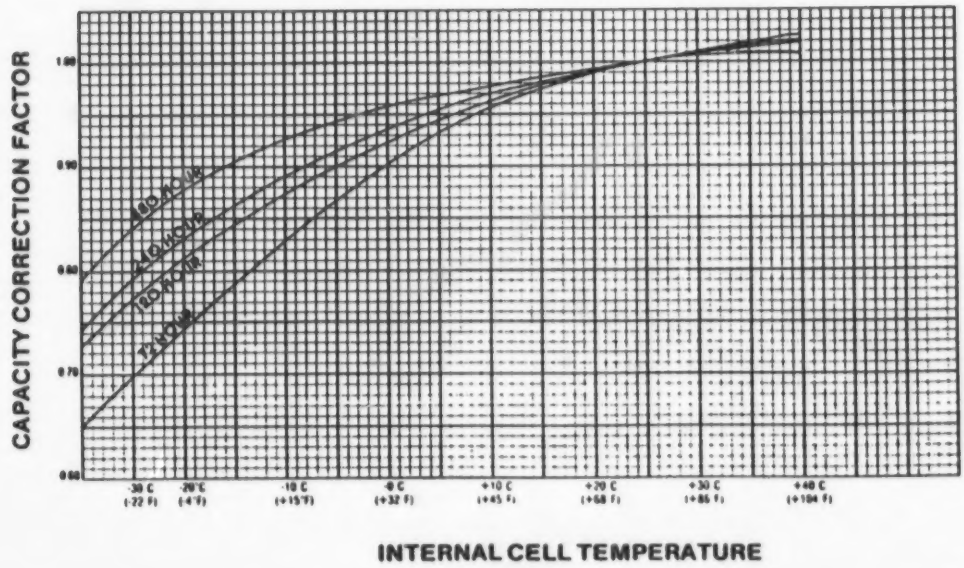
TYPE	VOLTS PER UNIT	NOMINAL A.H. CAP.	20 DAY (480 HR) A.H.	20 DAY (480 HR) AMPS	10 DAY (240 HR) A.H.	10 DAY (240 HR) AMPS	5 DAY (120 HR) A.H.	5 DAY (120 HR) AMPS	3 DAY (72 HR) A.H.	3 DAY (72 HR) AMPS	32°F (0°C) 500 HR A.H.
6E95-5	12	180	192	0.40	192	0.80	192	1.60	192	2.67	184
6E95-7	12	270	288	0.60	288	1.20	288	2.40	288	4.00	276
6E95-9	12	360	383	0.80	383	1.60	383	3.19	383	5.32	368
6E95-11	12	450	478	1.00	478	1.99	478	3.98	478	6.64	459
6E120-9	12	500	538	1.12	538	2.24	538	4.48	538	7.47	516
6E120-11	12	625	673	1.40	673	2.80	673	5.61	673	9.35	646
6E120-13	12	750	808	1.68	808	3.37	808	6.73	808	11.22	776
6E120-15	12	875	942	1.96	942	3.93	942	7.85	942	13.08	904
3E120-17	6	1000	1077	2.24	1077	4.49	1077	8.98	1077	14.96	1034
3E120-19	6	1125	1212	2.53	1212	5.05	1212	10.10	1212	16.83	1163
3E120-21	6	1250	1346	2.80	1346	5.61	1346	11.22	1346	18.69	1292
3E120-23	6	1375	1481	3.09	1481	6.17	1481	12.34	1481	20.57	1422
3E120-25	6	1500	1616	3.37	1616	6.73	1616	13.47	1616	22.44	1551
3E120-27	6	1625	1750	3.65	1750	7.29	1750	14.58	1750	24.31	1680
3E120-29	6	1750	1885	3.93	1885	7.85	1885	15.71	1885	26.18	1809

FINISHING CHARGE VOLTAGES: 2.65 VPC @ 77°F (25°C)

SELF DISCHARGE RATES: 2.0% PER MONTH AT 77°F (25°C)
12.0% PER MONTH AT 132°F (55°C)

MAXIMUM CONTINUOUS DISCHARGE RATES: E95-5 to 11, E120-9 to 15 } 150 AMPERES
E120-19 to 29 250 AMPERES

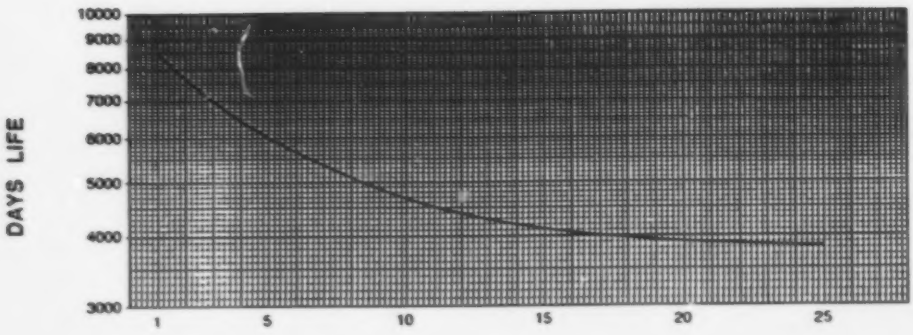
Temperature Adjustment



To correct for temperature variances (worst case condition) multiply the batteries rated capacity at 25°C (77°F) by the correction factor above to yield the expected capacity of the battery at a given temperature (internal cell temperature.) To use ambient air temperatures, average the temperature readings over a 24 hour period and use the correction factors above.

Days Life

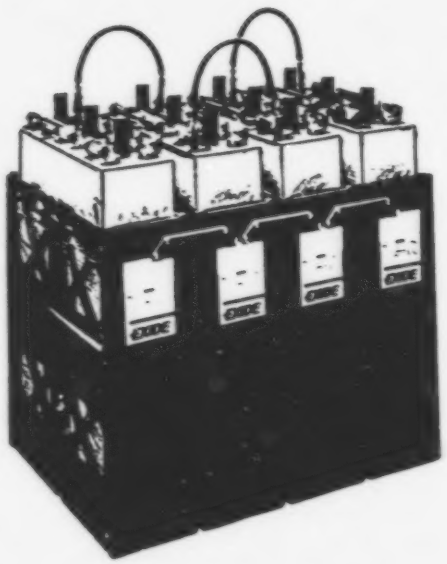
CYCLE LIFE VS. DEPTH OF DISCHARGE
One Cycle/Day



DAILY AVERAGE DEPTH OF DISCHARGE
(% of rated capacity)

Accessories

	CAT. NO.
HYDROMETER	81332
HYDROMETER HOLDER	27717
THERMOMETER	88330
FLAME ARRESTOR	89403
TRAY LIFTING DEVICE	84870
BOLT PACKAGE	80323
INTER-UNIT CONNECTORS E95-5 thru E95-11 E120-9 thru E120-15 E120-17 thru E120-29	 17635-14
NO-OXIDE GREASE 2 oz. (57 gm) 8 oz. (227 gm) 16 oz. (454 gm)	 82852 82853 82854
BURN-ON FLAG TERMINALS	81215
FLAME ARRESTOR W/ACID LEVEL INDICATOR E95 cells E120 cells	 89696 89697



EXIDE
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FORM 8235—2-83 Printed in USA

Type 802
Ampere-Hour Charge Control Meter

The Type 802 Ampere-Hour Charge Control Meter provides users with three major advantages: battery state of charge indication; simplified charging systems; and extended battery life through reduced overcharge.

The unit keeps a count of the current flowing in the battery circuit and is specifically designed for charge control application, giving a readout of battery capacity in terms of percentage of full charge. It also performs a number of additional functions, based on the ampere-hours and is powered by the circuit it monitors.

Other major benefits of the system:

- accurate charge control
- voltage insensitive control
- reduced maintenance schedule
- expanded supervisory control and monitoring
- load management — shedding

The unit offers many features. These include:

- programmable battery size — 1 to 999 AH or 10 to 9990 AH
- programmable 100mV shunt size — 5 to 1000 Amp or 50 to 10,000A
- programmable or automatic (temperature-based) efficiency compensation
- programmable decoded output — zero to 90 percent
- programmable charge hysteresis control (90 to 99%)
- decoded 80 percent output
- charging indicator
- high temperature charge inhibit
- analogue output for remote percent meter indication
- dual shunt input
- shunt integrity monitoring
- all programming customer adjustable on site
- simple application

SPECIFICATIONS

Electrical

Input:	
Voltage	12 to 240VDC Nominal (in 3 ranges)
Power	2W typical 3W maximum

Measurement

Input:	
Signal	± 100mV Nominal ± 250mV Peak
Shunt Calibration	5 to 1000A @ 100mV
Crest Factor	8 @ 100 Hz
Impedance	40K nominal (Diff)
Common Mode	± 5VDC 55dB rejection
Float Level	± 300VDC (Nominal)

Unit Accuracy

5 to 100mV	± 0.5% ± 1 digit
2 to 200mV	± 1% ± 1 digit
0.5 to 250mV	± 5% ± 1 digit
Temp Coefficient	0.025 x accuracy/°C outside range 10° to 40°C

Displays and Controls

Readouts	100.0% to 00 to -50.0% 3½ digit LED (15 mm)
Signals	Charging (battery) Battery temperature (option) Shunt Open (option)
Push-button	– 50 to 100% set and cycle

Output

Analogue Remote Signal	0 to 1mA (0 to 100% signal)
Charge Control Contact	Open at 100%; closed at < 90 to 99% (as set)
80% Capacity Contact	Closed at < 80%
0 to 90% Capacity Contact	Opened at < 0 to 90% (as set)

General

Alarm Contact	Closed below 00%, shunt open or temperature high
Temperature Alarm Signal	Opto-transistor (1mA maximum)

Ranges and Limits

Battery Capacity*	1 to 999 A H or 10 to 9990 A H

Input Shunt*	5, 10, 20, 50, 100, 200, 500, or 1000 Amps @ 100mV
Battery Efficiency*	1.0 to 1.8 (in .05 increments)
Charge Signal Hysteresis*	90 to 99% (in 1% increments)
Capacity Signal*	0 to 90% (in 10% increments)
Battery Self-discharge	0.5 or 1% per day (.05% standard)
Memory Retention	>45 days

*NOTE: Customer field programmable for application.

OPTIONS

Second Shunt Amplifier— monitors high current discharge circuit

Input	–100mV
Shunt Range	50 to 10,000A @ 100mV (Times 10 of Input Shunt)

Battery Temperature – monitor and compensation

Efficiency Compensation	1.0 to 1.8 (temperature dependent) times 1.1 at 80 to 100% capacity
Alarm Range	50° to 86° C
Alarm Signal	LED indicator Relay Signal (general alarm) Transistor Signal (1mA maximum) Charge Signal Inhibit

Shunt Monitor — monitors shunt circuit

Alarm Signal	LED indicator Relay Signal (general alarm)

General

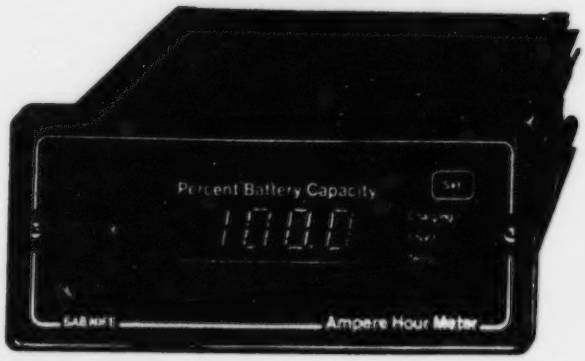
Relay Contacts	1 Amp – 50W to 250V maximum
Connector	Din 41612 Type C 32 pst A + C even

ENVIRONMENTAL

Temperature*

Operational	–25° to + 60°C
Storage	–50° to + 70°C
Humidity	to 95% non-condensing
Vibration	1G – 5 to 100 Hz 3G shock

*NOTE: not related to battery



MECHANICAL

Mounting	Panel or bulkhead	
Access	Front for all adjustments	
Dimensions (Approx.)	mm	20.5 D × 18.5 W × 90 H
	inches	8.0 D × 7.3 W × 3.5 H
Weight (Approx.)	kg	1.25
	pounds	2.75
Case	Aluminum housing ABS bezel Lexan lens	

TYPE 802 APPLICATION

The meter connects into the circuit like an ammeter. The current flow is monitored by the voltage drop developed across a series shunt and from this the battery charged capacity is determined.

When the battery needs recharging a signal is given to the charger which switches to a high rate and it returns to float when the required charge is replaced.

This method of charge control provides precise recharge, minimizing overcharge, reducing water consumption, and extending battery life. With charge control based entirely on battery current — and not on voltage as in other systems — simple charging methods can be used without risking thermal runaway.

The Model 802 Ampere-Hour Meter is available with a set of standard operational features in addition to a number of options which are supplied to customer requirements. These options are fitted at time of order.

STANDARD PACKAGE

Input Power
The AHM is powered by the circuit it monitors from 12 to 240VDC in 3 ranges. The nominal input voltage must be specified.

Operational Characteristics
The standard model has all the characteristics described in the specifications with the exception of the option list. It is fully programmable at site for shunt size, battery size (2 ranges), battery efficiency, capacity signal and charge hysteresis. Apart from input power, the battery self-discharge must be specified if different from the standard (0.5% per day), to 1% per day or none, and the battery capacity range. (1 to 999 or 10 to 9990 AH).

Controls
Integral push-button for initial setting and cycle testing of the AHM and relay outputs for auxiliary control.

Remote Indication
A scaled current output is standard for remote indication of battery capacity.

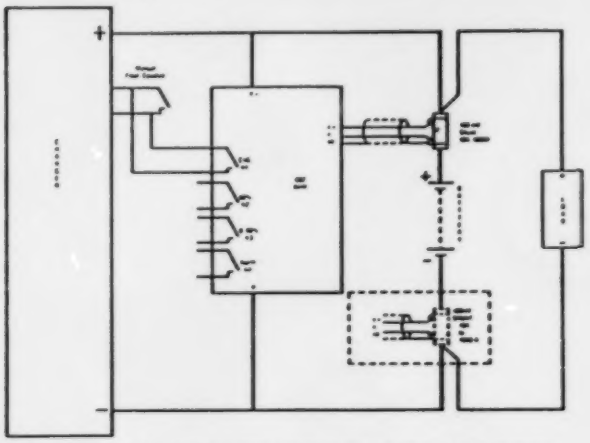
OPTION LIST

Second Shunt Amplifier
Used where the DC circuit includes a separate circuit for high current loads eg. Engine Starting. In this case a second shunt, 10 timers larger than the input shunt, is inserted in the high current DC circuit and wired back to the second shunt intput amplifier.

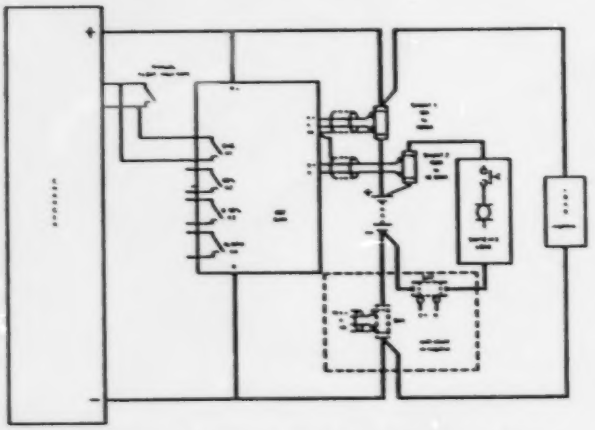
Battery Temperature
The battery temperature is monitored by a supplied sensor and used to adjust the battery efficiency factor with temperature to minimize overcharge and to inhibit the high rate signal in cases where the battery exceeds a predetermined temperature. This option is supplied factory adjusted for a specific battery type and application.

Shunt Monitor
Used to monitor the integrity of the shunt circuit, signalling an open or high resistance connection.

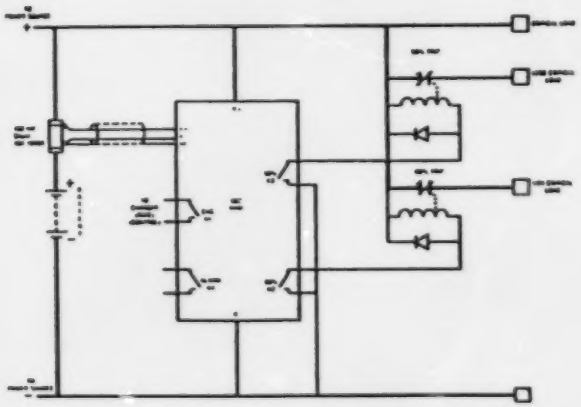
TYPICAL CONNECTION DIAGRAMS



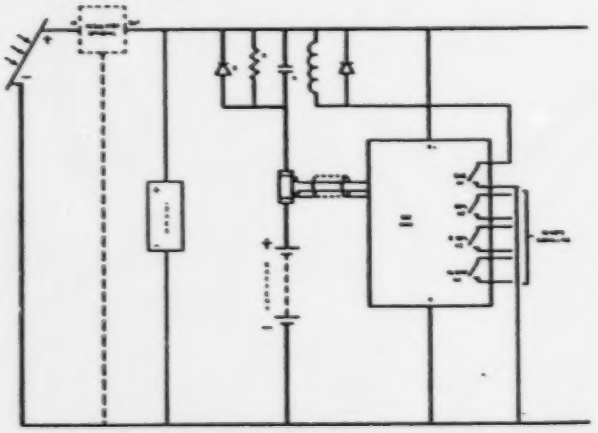
AMPERE HOUR CHARGE CONTROL OF FLOATING BATTERY APPLICATION (SHUNT IN POSITIVE OR NEGATIVE CIRCUIT)



AMPERE HOUR CHARGE CONTROL OF FLOATING/STANDBY BATTERY APPLICATION WITH SUPERVISORY AND HIGH CURRENT SWITCHED LOAD (EG. ENGINE STARTING)



LOAD SHEDDING APPLICATION TO PRESERVE BATTERY CAPACITY FOR CRITICAL LOADS OR TO LIMIT 'DEPTH' OF DISCHARGE



CHARGE CONTROL IN SOLAR POWER (OR WIND TURBINE) APPLICATION

TYPICAL SPECIFYING INFORMATION

The Ampere-Hour Meter shall be of solid state design utilizing 'floating' input analogue signal processing and digital integration techniques for integration of bipolar current flow. The digital display shall indicate the state of charge of the battery in percentage of full charge from 0 to 100% with a reserve of 0 to 50% for displaying reserve capacity of the battery. It shall have a typical accuracy plus or minus 1% or better.

The AHM shall be capable of instructing a high rate charge when the battery charge falls below a user selectable minimum (90 to 99%). It shall also incorporate auxiliary signalling for load management as required. The unit shall be programmable on site for such parameters as Shunt and Battery size (within ranges), Battery efficiency and low Capacity signal (0 to 90%). It shall incorporate Battery self-discharge compensation and have provision for remote indication of battery capacity.

It shall have a facility to enable the setting of any initial condition (ie. – 50 to 100%) and for cycling the AHM to exercise the system as a test procedure.

The Ampere-Hour Meter shall be a NIFE Model 802, to operate at _____ Volts, nominal, to monitor a battery in the range of _____ AH with self discharge compensation at _____% per day. The following optional accessories shall also be included:_____
_____
_____
_____

Specifications Subject To Change Without Notice.

SAB NIFE

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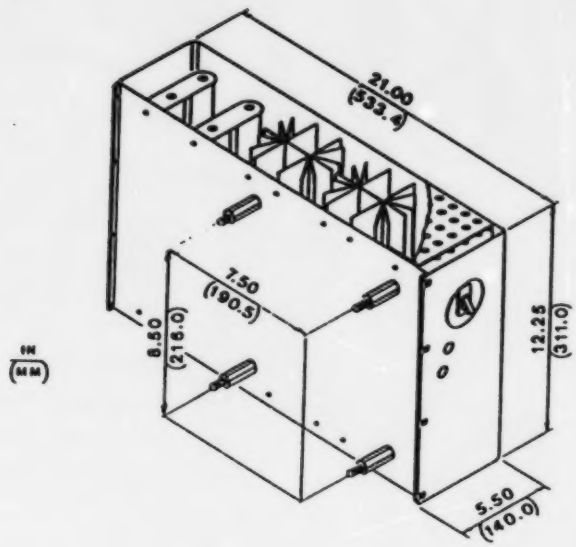

FIGURE 1.1 6720 Series Voltage Limiter Physical Description

TABLE 1.2 Product Specification

MODEL	VOLTAGE RANGE (V)	POWER RANGE (W)	(1) REG. (%)	(2) TEMP. COEFF. %/C	(3) RIPPLE
6720-12	13-18	0-720	0.25	.009	0
6720-24	24-30	0-720	0.25	.009	0
6720-48	48-60	0-720	0.33	.006	0

1) At 24°C, no load to full load regulation.
2) Average from -55°C to +55°C.
3) Pure DC source.

OVERLOAD PROTECTION: Limiter is in parallel with the TEG, therefore the internal resistance of the TEG limits the circuit current.
REVERSE CURRENT PROTECTION: Protected by a diode in series with output.
OPEN CIRCUIT: The open circuit voltage cannot rise above the limiter set-voltage.
VOLTAGE SENSING RELAY: The limiter is equipped with a standard Voltage Sensing Relay (VSR). The VSR provides a set of contacts which indicate an alarm condition when the output voltage drops below a preset minimum.

APPENDIX B

SAMPLE DATA PRINTOUT

TEST DATA - HYBRID SYSTEM with LTEG Data : 6 28 88

Time	Gross P.	Net P.	I. P.	Batt. I.	Batt. V.	Load P.	% Batt	Amb. T	Fin T	In. T
7h: 46m	0.0W	0.0W	5.3A-	2.6A	12.2V	88.5W	70%	+25C	+ 27C	+26C
7h: 52m	0.0W	0.0W	5.3A-	2.6A	12.2V	88.5W	70%	+23C	+ 27C	+27C
7h: 58m	0.0W	0.0W	5.4A-	2.5A	12.2V	88.5W	70%	+23C	+ 27C	+26C
8h: 5m	0.0W	0.0W	6.0A-	1.9A	12.2V	88.7W	70%	+25C	+ 27C	+27C
8h: 11m	0.0W	0.0W	7.0A-	0.9A	12.3V	89.0W	70%	+24C	+ 27C	+26C
8h: 17m	0.0W	0.0W	8.9A	1.0A	12.3V	89.7W	70%	+24C	+ 27C	+27C
8h: 23m	0.0W	0.0W	9.7A	1.7A	12.4V	90.2W	70%	+23C	+ 27C	+27C
8h: 29m	0.0W	0.0W	9.5A	1.6A	12.4V	90.3W	70%	+23C	+ 27C	+27C
8h: 35m	0.0W	0.0W	10.1A	2.1A	12.4V	90.6W	70%	+22C	+ 27C	+27C
8h: 41m	0.0W	0.0W	10.6A	2.6A	12.5V	90.8W	70%	+23C	+ 28C	+27C
8h: 48m	0.0W	0.0W	10.6A	2.7A	12.5V	91.1W	70%	+22C	+ 28C	+27C
8h: 54m	0.0W	0.0W	12.6A	4.6A	12.5V	91.8W	70%	+23C	+ 27C	+27C
9h: 0m	0.0W	0.0W	13.9A	6.0A	12.6V	92.4W	70%	+21C	+ 28C	+27C
9h: 6m	0.0W	0.0W	14.0A	6.0A	12.6V	92.6W	70%	+22C	+ 28C	+28C
9h: 12m	0.0W	0.0W	14.3A	6.4A	12.7V	92.8W	70%	+21C	+ 27C	+28C
9h: 18m	0.0W	0.0W	14.6A	6.6A	12.7V	93.0W	70%	+21C	+ 28C	+28C
9h: 24m	0.0W	0.0W	14.8A	6.8A	12.7V	93.1W	70%	+23C	+ 28C	+28C
9h: 30m	0.0W	0.0W	16.4A	8.4A	12.7V	93.6W	70%	+23C	+ 28C	+28C
9h: 37m	0.0W	0.0W	16.5A	8.5A	12.7V	93.7W	70%	+23C	+ 29C	+28C
9h: 43m	0.0W	0.0W	17.1A	9.1A	12.7V	93.8W	70%	+24C	+ 29C	+28C
9h: 49m	0.0W	0.0W	15.1A	7.1A	12.7V	93.4W	70%	+23C	+ 28C	+29C
9h: 55m	0.0W	0.0W	14.5A	6.6A	12.7V	93.1W	70%	+24C	+ 29C	+28C
10h: 1m	0.0W	0.0W	18.0A	10.0A	12.8V	94.1W	70%	+23C	+ 29C	+28C
10h: 7m	0.0W	0.0W	16.0A	8.1A	12.7V	93.7W	70%	+23C	+ 29C	+29C
10h: 13m	0.0W	0.0W	17.8A	9.8A	12.8V	94.2W	70%	+24C	+ 30C	+29C
10h: 20m	0.0W	0.0W	12.5A	4.6A	12.7V	92.8W	70%	+23C	+ 29C	+29C
10h: 26m	0.0W	0.0W	6.7A-	1.1A	12.5V	91.0W	70%	+23C	+ 29C	+29C
10h: 32m	0.0W	0.0W	7.8A-	0.1A	12.5V	90.9W	70%	+23C	+ 30C	+29C
10h: 38m	0.0W	0.0W	20.9A	12.9A	12.8V	94.6W	70%	+24C	+ 29C	+29C
10h: 44m	0.0W	0.0W	24.7A	16.7A	12.9V	96.2W	70%	+24C	+ 29C	+29C
10h: 50m	0.0W	0.0W	24.7A	16.7A	12.9V	96.3W	70%	+24C	+ 30C	+30C
10h: 56m	0.0W	0.0W	24.9A	16.9A	13.0V	96.5W	70%	+25C	+ 30C	+29C
11h: 3m	0.0W	0.0W	25.3A	17.3A	13.0V	96.7W	70%	+25C	+ 30C	+30C
11h: 9m	0.0W	0.0W	25.7A	17.7A	13.0V	96.9W	70%	+25C	+ 30C	+30C
11h: 15m	0.0W	0.0W	25.9A	17.8A	13.0V	97.0W	70%	+25C	+ 30C	+30C
11h: 21m	0.0W	0.0W	26.4A	18.4A	13.0V	97.2W	70%	+26C	+ 30C	+30C
11h: 27m	0.0W	0.0W	26.3A	18.2A	13.0V	97.3W	70%	+25C	+ 30C	+30C
11h: 33m	0.0W	0.0W	28.3A	20.3A	13.1V	98.0W	70%	+26C	+ 30C	+30C
11h: 39m	0.0W	0.0W	26.5A	18.5A	13.1V	97.7W	70%	+26C	+ 30C	+30C
11h: 45m	0.0W	0.0W	15.3A	7.3A	12.9V	94.3W	70%	+27C	+ 30C	+31C
11h: 51m	0.0W	0.0W	15.8A	7.8A	12.9V	94.4W	70%	+26C	+ 31C	+31C
11h: 57m	0.0W	0.0W	22.7A	14.2A	13.0V	96.1W	70%	+26C	+ 31C	+31C
12h: 3m	0.0W	0.0W	23.9A	15.8A	13.1V	97.0W	70%	+27C	+ 31C	+31C
12h: 9m	0.0W	0.0W	26.6A	18.4A	13.1V	97.9W	70%	+26C	+ 31C	+32C
12h: 15m	0.0W	0.0W	28.5A	20.5A	13.2V	98.6W	70%	+27C	+ 31C	+32C
12h: 21m	0.0W	0.0W	29.4A	21.4A	13.2V	99.1W	70%	+27C	+ 31C	+32C
12h: 28m	0.0W	0.0W	30.6A	22.4A	13.3V	99.6W	70%	+28C	+ 31C	+32C
12h: 34m	0.0W	0.0W	26.5A	18.1A	13.2V	98.5W	80%	+27C	+ 32C	+32C
12h: 40m	0.0W	0.0W	27.6A	19.2A	13.2V	98.8W	80%	+28C	+ 32C	+32C
12h: 46m	0.0W	0.0W	18.5A	10.5A	13.1V	96.1W	80%	+28C	+ 32C	+32C
12h: 52m	0.0W	0.0W	16.3A	8.3A	13.0V	95.3W	80%	+27C	+ 33C	+33C
12h: 58m	0.0W	0.0W	12.7A	4.8A	12.9V	94.0W	80%	+27C	+ 33C	+33C
13h: 4m	0.0W	0.0W	13.1A	5.2A	12.9V	94.0W	80%	+28C	+ 33C	+33C
13h: 10m	0.0W	0.0W	12.1A	4.1A	12.8V	93.7W	80%	+28C	+ 33C	+33C
13h: 16m	0.0W	0.0W	19.6A	10.7A	13.0V	95.7W	80%	+28C	+ 33C	+33C
13h: 22m	0.0W	0.0W	23.4A	14.7A	13.2V	97.6W	80%	+30C	+ 34C	+33C
13h: 28m	0.0W	0.0W	23.6A	14.2A	13.2V	97.6W	80%	+29C	+ 34C	+34C
13h: 34m	0.0W	0.0W	14.7A	6.8A	13.0V	95.0W	80%	+27C	+ 34C	+34C

I Panel 1024.8 I Batt - 10.5 I Batt 567.9